AMERICAN SEWERAGE PRACTICE

VOLUME II

CONSTRUCTION OF SEWERS

AMERICAN SEWERAGE PRACTICE

THREE VOLUMES

BY

METCALF AND EDDY

VOL. I —DESIGN OF SEWERS
747 pages, 6 × 9, 328 illus., 72 tables.

VOL. II —CONSTRUCTION OF SEWERS
564 pages, 6 × 9, 181 illus., 81 tables.

VOL. III —DISPOSAL OF SEWAGE
877 pages, 6 × 9, 234 illus., 210 tables.

AMERICAN SEWERAGE PRACTICE

VOLUME II

CONSTRUCTION OF SEWERS

BY

LEONARD METCALF

AND

HARRISON P. EDDY

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BEN
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PREFACE

The construction of a sewerage system involves attention to many apparently unimportant details which, if neglected, may materially diminish the value of the works. If the alignment and grades are not true, there may be places where the velocity of the sewage will be checked and deposits of sand and organic matter will occur. These not only reduce the capacity of a sewer, but if they remain for some time the organic matter decomposes and thus affects injuriously the sewage flowing over it, which should reach the place of disposal or treatment as fresh as possible. If the inner surfaces of sewers are not so smooth as contemplated by the designer, the resistance to the flow of the sewage is increased and the sewers will not have the desired capacity. In order to avoid these and other defects, the field engineering and inspecting force must insist on many things which are discussed in this volume but have been rarely taken up in books or papers on sewerage.

In addition to acting as designing and supervising engineers upon work executed by contract, the authors have had direct charge of the construction by day labor of many miles of sewers, large and small, in earth and rock, trench and tunnel. The construction of sewers from the contractor's point of view is, therefore, understood clearly by them. They have endeavored to present in the following pages the instructions they would issue to the superintendents and foremen in charge of day-labor forces, and the advice they would give to contractors taking up sewer construction for the first time. The authors believe that there is need of improvement in much of the sewer work done in this country and that this improvement should be made in inspection as well as in the operations carried on by contractors, in construction done by day labor as well as in that executed by contract. Their experience has been that contractors generally have desired to do only the best work, but that they sometimes fell short of attaining their object through unfamiliarity with the special requirements for good sewers. It is hoped that this book will prove helpful to all such men, as well as to engineers and inspectors who should be familiar with practical methods of construction.

Leonard Metcalf.
Harrison P. Eddy.

14 Beacon Street,
Boston, Mass.
Sept. 11, 1914.

CONTENTS

PAGE
PREFACE v

CHAPTER I

PRELIMINARY INVESTIGATIONS 1

Maps for preliminary investigations—Field work—Examination of existing structures—Character of soil—Borings—Jet drilling—Core drilling—Frequency of borings—Surface conditions—Maps and profiles—Contract, specifications and drawings—Organization of engineering department for construction.

CHAPTER II

ENGINEERING WORK AND INSPECTION DURING CONSTRUCTION. . . 25

Laying out trench work—Reference marks—Transferring line to the sewer—Grades—Laying out disposal works and similar structures—Supervision and inspection—Pipe—Cement—Sand—Crushed stone and gravel—Brick—Reinforcing steel—Excavation—Backfilling—Removal of sheeting—Final inspection—Leakage—Relations of engineers and inspectors to the contractor—Estimates—Records—Cost keeping—Printed forms—Progress—Cost of engineering and supervision.

CHAPTER III

EXCAVATION 54

Material to be excavated—Classification—Definitions of rock excavation—Hand excavation—Loosening surface—Opening trench in frozen ground—Preserving pavements—Excavated material—Tunneling—Work in different materials—Lighting—Ventilation—Handling and transporting materials—Shafts—Methods of tunneling in soft ground—Methods of tunneling in rock—Pumping, bailing and underdrainage—Settlement of adjacent structures.

CHAPTER IV

MACHINERY FOR TRENCH EXCAVATION 82

When machines are economical—Carson trench machine—Potter trench machine—Potter excavator and conveyor—Cableways—Carson-Trainor hoister and conveyor—Steam shovels—Endless chain machines—Drag scrapers—Derricks and cranes—Excavating buckets—Economical use of machinery.

CHAPTER V

PAGE

METHODS OF ROCK EXCAVATION 101

Hand drilling—Spacing drill holes—Cleaning holes—Rotary or core drill—Reciprocating or percussion drill—Electric-air drill—Hammer drill—Limits of the several methods of drilling—Drill bits—Drill sharpeners—Portable air compressors—Handling rock.

CHAPTER VI

EXPLOSIVES AND BLASTING 129

Black powder—Contractors' powder—Dynamite—Ammonia powder—Gelatine dynamite—Cartridges—Rapidity of action—Selection and economical use of explosives—Effect of fumes—Explosives in wet holes—Freezing and thawing dynamite—Loading holes—Exploders and fuses—Stemming and tamping—Unloading holes—Blasting machines—Wiring—Shipment and storage of explosives—Magazines—Cost of dynamite.

CHAPTER VII

QUANTITY AND COST OF EXCAVATION 151

Effect of materials on width of trench—Lines of excavation—Narrowed bottom of trench—Excess excavation—Measurement of excavation—Cost of excavation in general—Cost of Louisville sewerage project—Engineer's estimates and actual costs—Force account costs—Local contractors' bids—Cost of excavation and backfilling, Denver—Cost of complete sewers, Louisville—Cost of earth and rock excavation, Louisville—Cost of concrete and steel in sewers, Louisville.

CHAPTER VIII

RATE OF PROGRESS IN BUILDING SEWERS 195

Influence of conditions—Tabulation of records on tunnels—Rate with machine at Denver—Rates of excavation and placing concrete at Louisville.

CHAPTER IX

THE SHEETING AND BRACING OF TRENCHES AND TUNNELS . . . 214

Necessity for shoring trenches—Vertical sheeting—Bill of materials for trenches of different depths and widths—Examples of shoring—Box sheeting—Poling boards—Stay bracing—Pulling sheeting—Kinds of lumber—Dressing lumber—Steel sheet piling—Timbering tunnels—Timbering tunnels in gravel and sand—Timbering large tunnels—Tunneling with shield and compressed air—Tools required—Practical suggestions on timbering.

CHAPTER X

PAGE

SIZES OF SHEETING, RANGERS AND BRACES 267
Need of shoring different materials—Cohesion—Lack of adhesion—Tendency of soil conditions to change—Rankine's formula—Hydrostatic pressure—Meem's theory of earth pressures—Calculation of sizes of rangers and braces.

CHAPTER XI

PURCHASING, HANDLING AND LAYING SEWER PIPE 291
List prices—Discounts—Inspection—Tests—Handling and storing pipe—Laying pipe—Branches—Iowa pipe-laying requirements—Cost of laying pipe—Rate of pipe-laying—Laying large concrete pipe—Laying cast-iron pipe—Laying steel pipe—Subaqueous pipe laying—Laying pipe from supports—Floating pipe—Pulling pipe into place.

CHAPTER XII

JOINTING SEWER PIPE 330
Materials for joints—Cement joints—Sulphur and sand joints—Asphalt and tar joints—G.-K. compound—Tests of pipe after laying.

CHAPTER XIII

CONSTRUCTION OF BRICK AND BLOCK SEWERS 347
Competitive bids on alternative materials—Quality of workmanship—Use of pipe and masonry sewers—Tests of sewer brick—Handling brick—Mortar—Brick laying—Quantities of materials required—Rate of progress—Cost of brick sewers—Vitrified block sewers—Concrete block sewers—Construction of manholes.

CHAPTER XIV

CONSTRUCTION OF CONCRETE SEWERS 367
Advantages of concrete—Disintegration of concrete by chemical action—Use of materials excavated from trench—Quantities of sand, stone and cement—Mixing concrete by hand—Machine mixing—Placing concrete—Placing reinforcement—Waterproofing—Work joints—Placing concrete in freezing weather—Rate of progress—Cost of sewers.

CHAPTER XV

PROFILES, TEMPLATES, FORMS AND CENTERS 396
Definitions—Centers and profiles for brick, stone and block sewers—Wooden forms for concrete sewers—Metal-covered wooden forms—Steel forms for concrete—Forms for sewers

PAGE

built of concrete and brick or blocks—Building concrete sewers in one or more operations—Full-round wood forms for building concrete sewers at one operation—Forms for manholes—Forms for curves and junctions—Lumber for wood forms—Cost of steel forms—Cleaning forms preparatory to pouring concrete—Lubrication of forms—Length of time forms should be left in place—Handling forms.

CHAPTER XVI

CONTRACTS, SPECIFICATIONS AND DRAWINGS 433

Essentials of a contract—Arbitration—Advertisement of contract—Information for bidders—Form of proposal—Form of bidder's bonds—Contract—Insurance—Workmen's compensation—Liability insurance—Kinds of contracts—Unit price contracts—Lump sum contracts—Percentage contracts—Cost plus fixed sum contracts—Liquidated damages and bonus clauses—Contract drawings—Authors' form of contract—Typical general specifications.

CHAPTER XVII

TECHNICAL SPECIFICATIONS 465

Numbering clauses—Excavation—Shoring—Blasting—Pumping, bailing and draining—Backfilling—Piling—Foundations—Cement—Sand, gravel and broken stone—Mortar—Billet-steel concrete reinforcement bars—Rail-steel concrete reinforcement bars—Iron castings—Brick masonry—Concrete, plain and reinforced—Vitrified pipe and specials—Cement concrete sewer pipe—Pipe laying—Laying cast-iron pipe—Inlets and catch-basins—Manholes and wellholes—Curbing, gutters and sidewalks.

CHAPTER XVIII

OPERATION AND MAINTENANCE OF SEWERAGE SYSTEMS 491

Investment in sewers—Inspection—Deposits in sewers—Flushing sewers—Removing roots from sewers—Removal of heavy deposits from sewers—Cleaning and care of catch-basins—Repairs—Regulators and inverted siphons—Records—Cost of operation and maintenance of sewerage systems.

CHAPTER XIX

EXPLOSIONS IN SEWERS 527

Sources of inflammable gases and explosions—Pittsburg explosion—New York explosions—Boston explosion—Behavior of gasoline in sewers—Sources of ignition—Prevention of explosions—Safety precautions—Ordinances and regulations governing discharge of inflammable liquids—Other dangers.

INDEX 543

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AMERICAN SEWERAGE PRACTICE

CHAPTER I

PRELIMINARY INVESTIGATIONS

Many sewers have been built without much engineering assistance and when isolated and grades have been steep they have served their purpose fairly well. If, however, a municipality requires a system of sewers, it is of the utmost importance that it be designed and its construction supervised by an engineer of experience in this kind of work. This chapter has been prepared mainly with a view to giving helpful suggestions to the student, to the young engineer taking up sewerage engineering and to the inspector, and to presenting an outline of the steps taken by the engineering department of a comprehensive sewerage project. Some details and refinements are suggested which have doubtless often been omitted, and some of them may not be required upon small projects, but if a high grade of construction is to be secured the quality of the engineering must be equally high. It is a most common error to save a few dollars upon engineering work and lose hundreds or thousands of dollars upon the construction of sewer systems poorly designed. The average citizen does not know whether a sewer is 5 ft. deeper than necessary, contains 25 per cent. more masonry than is required, or is adequate for only 10 years when it should provide for a period of 30 years, but he can readily detect an extra inspector or a few hundred dollars spent upon a topographic survey which will enable the engineer to study his problems intelligently. One of the important duties of the engineer is, therefore, to instruct and educate commissions, committees, city councils and the public as to the necessity and value of a high grade of engineering work.

Considerable attention is given to the necessity and desirability of preparing adequate plans and of preserving records which shall be of value after the work in hand has been completed. Surprising as it may seem to some engineers, there are many municipalities in this country which do not possess even the most obviously necessary records of their sewers, such as those of their sizes and slopes. This is a condition which can be remedied only at great expense, if the system has been built many years. An illustration of this kind is furnished by the underground survey carried out under Henry M. Waite, Chief Eng. of the Department of Public Service of the city of Cincinnati, at a cost of more than $70,000. To secure information for the records prepared by this survey, it was necessary to make a manhole to manhole inspection of the sewers, measuring their diameters and securing elevations from which their slopes could be computed.

MAPS FOR PRELIMINARY INVESTIGATIONS

While the engineering force is being organized, a diligent search should be made to obtain all available existing maps which may have a bearing upon the contemplated work.

The United States Geological Survey has prepared maps showing the topography of a considerable portion of the United States. These are published in 20 X 16–1/2-in. sheets, the unit of area being a quadrangle 15 min., 30 min. or 1 deg. in extent each way. The scales are therefore 1 to 62,500, 1 to 125,000, or 1 to 250,000, which are almost equivalent to scales of 1 in., 1/2 in., or 1/4 in. to the mile respectively. These maps are sold by the Director of the Survey at Washington, D. C., for 10 cents per sheet, or, in quantities of fifty or more, at the rate of 6 cents per sheet. They will be of value in computing areas of very large drainage basins, such as those of creeks and rivers, and in showing the general topography of the community as a whole, but they are valueless for use in laying out individual sewers.

Street Maps.—City engineers, town surveyors, local assessment boards and land title companies frequently have maps of their localities. These often indicate not only street lines, but lot lines and buildings.

It is usually important to note the exact location of all pipes and conduits, which can sometimes be done through the aid of maps prepared by the public service corporations.

In many districts post route maps may be had, drawn to scales varying from 4 to 12 miles per inch, showing highways, railroads, ponds, rivers, streams, and range, township, section and meridian lines, in addition to the postal routes. These are oftentimes extremely useful in preliminary studies.

Although too much dependence should not be placed on the accuracy of county atlas maps, these also are of considerable service in connection with the preliminary work.

If upon checking up such maps they are found to be substantially correct, they may be used as a foundation for more extended mapping of the locality. Frequently little is saved by making use of such maps, unless they are found to cover a considerable portion of the district to be surveyed.

FIELD WORK

Having determined the scope of the work and the data required, unless satisfactory maps are available, surveys of the district must be made. The degree of precision required will be determined by conditions of the problem. If the expense is justified, it is desirable to establish a triangulation system which will furnish the skeleton for further filling-in surveys. The latter should include the precise location of street and property lines; street car tracks; water, gas, sewer and drain pipes; fire hydrants; conduits for electric lighting, telephone, telegraph and heating service; all pavements, noting character and approximate age; tunnels, subways, and culverts; public parks, play grounds, boulevards; all bodies of water, lakes, ponds, streams, brooks and important ditches, and other natural features or artificial structures which may be of importance to the problem in hand or influence the design of the new works.

Preliminary to taking the profiles, an accurate, permanent, and complete system of bench levels should be established throughout the entire area to be covered by the proposed sewerage system. The bench marks should be on points easily described, readily accessible, and that are not likely to be disturbed. They should be located at sufficiently close intervals for subsequent use; for instance, in heavy work one bench to each block in all streets where sewers are to be laid, and at frequent intervals where topographic details are to be obtained subsequently.

In establishing these benches it is desirable to run several circuits covering the entire area, thus establishing bench marks of primary order. Each circuit may thus be checked independently, and inaccuracies of the field work within each circuit detected. The accuracy with which such circuits should close depends in great measure upon the quality of construction work to be obtained and the flatness of the grades to be used in the work.

The Board of Water Supply for the City of New York, in establishing the bench marks for its Catskill Aqueduct Line,[1] established the requirement that circuits should close with an error in feet less than $0.02\sqrt{\text{miles}}$. On this work the 15-in. Berger inverting dumpy level with stadia wires set for a ratio 1:200 was used. Two self-reading, white pine level rods, 10 ft. long, were used. These rods were similar to the Molitor rod (*Trans. Am. Soc. C. E.*, vol. xlv, page 14) except that they were divided into tenths and two-hundredths of a foot, the tenths being numbered consecutively. Each rod was shod with a phosphor-bronze shoe, terminating in a cylindrical pin about 3/4 in. in diameter and about 1 in. long, the bottom face of this pin being accurately faced in a plane normal to the axis of the rod. The rod was also provided with a mercurial thermometer, a watch glass level capable of easy adjustment, and provision for the hanging of a plumb-bob.

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[1] See "Bench Leveling Operations on the Catskill Aqueduct Line," by M. E. Zipser, *Engr. News*, Feb. 20, 1908.

In order to obtain the speed and accuracy required, two rodmen were employed to hold on alternate turning points, these points being selected so as to make back sights and fore sights practically equal. The level was protected from the rays of the sun by an umbrella. Each of the two stadia wires was read and recorded in addition to the ordinary level reading, and these several readings reconciled before moving ahead. The speed obtained on this work averaged about 2 miles per day in rugged or wooded country and 4 miles per day in comparatively level and open country, while check levels were run at the rate of about 1 mile per hour. The adjustments of the instrument were tested at least once per week, although actually no adjustments were required.

In ordinary work with flat surfaces this is a desirable and readily attainable standard. In small cities in a rolling or hilly country a lower standard of accuracy may suffice. Having obtained the primary bench marks, intermediate bench marks within the area embraced by each circuit can then be established, care being taken to check each cross line with benches of the primary order.

Profiles should be run on all existing streets and alleys, and along the location of all proposed streets. Levels may be taken in the center of the street at intervals of 100 ft., and at such intermediate points as the changing of grades may require. For all proposed streets, the proposed grade should be ascertained, provided it has already been "established."

Where sewers exist, sufficient levels should be taken in their inverts to determine the accuracy of the profiles which are on record, if there be doubt of their accuracy, and if these are found to be incorrect, or if none exist, an accurate profile should be made by taking levels of the invert at each manhole. This may require the use of a very long pole, graduated in feet, tenths and hundredths, shod with a steel point for penetrating the sediment in the sewer.

Topography notes should be obtained for the preparation of a map showing the topography of the entire city, with contour intervals of 1, 2-1/2, 5 or 10 ft., according to the slopes of the ground surveyed. This map should include the area within the present city limits and such suburban territory as is likely to be annexed within the next 30 to 50 years. If possible, it should also cover such contiguous territory as may drain through or into the city.

The approximate cross-section of the streets should be determined and the elevation of the sills of buildings along the street, more particularly of the low-lying ones. Similarly the approximate depth of the cellars should be noted, in order that the sewers may be laid out so as to drain the cellars of all houses.

The elevations should be taken of the beds of all streams and inverts of canals or culverts encountered, and the various water levels or stages should be recorded, the minimum, mean low, mean high, and maximum flood levels.

Examination of Existing Structures.—It is desirable to locate by means of test pits the elevations of all pipes and conduits which are likely to be encountered in the construction of the proposed sewers, unless they are clearly and accurately shown upon the drawings which purport to show these structures.

The accuracy of such drawings as have been procured should be determined before making use of them.

The existing sewers should be examined to determine their physical condition, the deposits in and leakage into them.

For physical examination of the sewers it is frequently possible, by means of two mirrors, to reflect sufficient sunlight into the sewers to enable one to determine the quality of the workmanship, the location of imperfections in the construction of the sewers, and the location of foreign matter contained therein. Under this method one man stands upon the surface of the ground and reflects the sunlight down to a mirror held by a man in the bottom of the manhole, who stands, figuratively speaking, upon his head, and flashes these rays into the sewer, and at the same time examines its interior. Good mirrors, 5 in. in diameter, which can be carried in the pocket will be found convenient for this purpose. An electric lamp deriving current from a battery may be floated through from manhole to manhole. A lighted lamp or candle should not be used for this purpose because of the danger of explosion.

At times when sunlight is not available, and where incandescent electric lighting circuits are convenient, it is frequently possible, by means of long extension cords, to make this examination by means of powerful tungsten lamps equipped with good reflectors, although such light cannot be thrown as far as good reflected sunlight.

The amount of ground-water leakage, if sufficient to warrant its measurement, can often best be determined by means of weirs within the manholes, due allowance being made for velocity of approach.

Run-off Data.—The river or stream flow is often of great importance, particularly in connection with problems involving the disposal of sewage. For its study there should be obtained, first, the drainage or catchment area; second, the rainfall records; third, the run-off or discharge records; fourth, rainfall and run-off records of other similar or comparable drainage areas in the neighborhood.

Where reliable records of stream flow are not available, it is desirable to establish gaging stations upon such streams early in the investigation, in order to secure as long and complete a record of discharge as possible. Such measurement should surely cover the dry-weather flow of the year in which the investigation is made, and should be continued throughout the entire period of investigation.

In connection with such stream-flow measurements, it is very important that the site of the gaging station be selected only after careful and thoughtful consideration of all available places. It is important that the channel should be straight with approximately uniform cross-sections for several hundred feet above and below the site selected. The bed of the stream at that point should be fairly permanent and of regular shape. It should be a sufficient distance above any dam or the junction with any other stream to be free from the effect of backwater, and be reasonably accessible during all stages of the stream.

A permanent gage should be established at the outset, in such a position that it may serve its purpose during all ranges of depth of water which are likely to occur, and its location should be such as to permit of its being read at all such stages.

This gage should be read and recorded daily, and more frequently when the flow is fluctuating with considerable rapidity.

The cross-section of the stream should be determined at the beginning and remeasured from time to time during the season, in order to ascertain what changes, if any, have taken place. Especially should this be done after all floods, at which times the section may be changed, either by erosion or by sedimentation.

The velocity of flow should be determined frequently, and especially during the summer low-water stage. The velocity may be determined by a current meter, by floats, or, where small flows exist, it may be computed from the flow measured by a weir.

From the velocity of flow determined for various stages of the river, a rating curve may be prepared, from which the flow may be estimated for the intermediate depths of water, with a limit of error of about 5 per cent.

Coincident with the records of stream flow, the rainfall near the gaging station and at numerous places scattered over the drainage area of the stream in question should be recorded.

Character of Soil.—The character of the soil should be determined, in order that the cost of the work may be estimated with as fair a degree of accuracy as practicable. For this purpose, information may be obtained by inquiry of local parties who have made excavations or sunk wells, and also by means of soundings, drillings, and borings.

For shallow determinations, approximate information may be obtained by driving a solid steel rod or a pipe fitted with a steel point and a driving head. If the ear is placed close to the rod as it is driven, it is possible, after a little practice, to determine when the point passes into and through soils of various grades, such as clay, sand and gravel. The man holding the rod can distinguish between different materials in a similar manner. By withdrawing the rod from time to time and examining its point, minute samples may be obtained, especially if a slight groove has been cut in the driving point. Such a rod may be withdrawn by means of a long lever and chain, or by means of a friction clutch, Fig. 1, having a large ring attached to one end into which the end of a lever may be slipped.

The methods and cost of making 1435 ft. of punch borings in 116 holes at St. Louis, Mo., were described by W. W. Horner in *Engineering News*, Sept. 5, 1912. The borings were made by a gang of four men using 7/8-in. steel rods 12 ft. in length. A boring point was screwed into the lower end. It was about a foot long and tapered from a shoulder somewhat larger than the rod to a fine point. Another point called the "punching rod" was practically a churn drill and was used to punch through strata of hardpan or obstructions which were encountered. In boring, two men usually rode the handle bar, while two others turned the rod. In hard ground a small quantity of water was used to soften the clay and lubricate the hole. The rods were removed at intervals of 5 ft., the point being replaced by a spoon with which a sample was taken. In soft ground the samples were not of much value, as the hole might close in and the spoon become partially filled before reaching bottom. In firm material a true sample could be obtained if proper care were used. Rock was detected by the ring, which indicates to those familiar with the work whether a boulder or ledge is encountered.

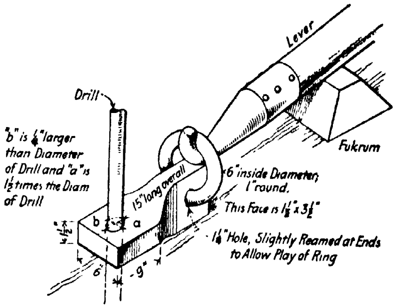
Lever
Drill
"b" is ¼" larger than Diameter of Drill and "a" is 1½ times the Diam of Drill
Fukrum
6" inside Diameter, 1" round.
15" long overall
This Face is 1½" x 3½"
b
a
1½"
1¼" Hole, Slightly Reamed at Ends to Allow Play of Ring
6"
9"

FIG. 1.—Friction clamp for drawing drill.

Mr. Horner stated that the cost of this work was higher than usual, because of the character of earth encountered; about 300 ft. of boring was through hard shale, 40 ft. through old macadam road, and of the remainder, about half was through very hard clay and gravel. The depth of holes was 13 ft. average, 2 ft. minimum, and 39 ft. maximum.

The total labor amounted to 180 days, equivalent to 45 days' work for one gang of four men. The average depth bored was 32 ft. per gang per day, which cost 24 cents per linear foot of boring. Such work through ordinary clay and loam costs from 6 to 10 cents per foot for holes averaging 15 ft. deep, according to Mr. Horner.

Borings.—Samples of earth, sand, and gravel may be obtained from depths not exceeding 15 to 30 ft., by means of post-hole augers or even with an ordinary carpenter's auger welded to a steel rod or gas pipe and operated by a handle formed by a plumber's tee into which two short pieces of pipe have been threaded, one on either side, which serve as handles. This auger will probably work to better advantage if the center point is removed, Fig. 2.

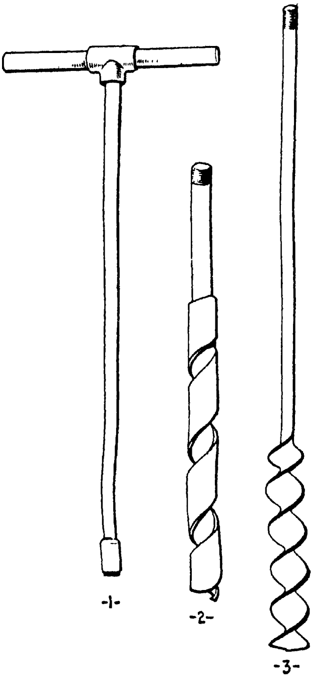

Fig. 2.—Auger handle and bits.

Jet Drilling.—In the jet drilling method, a pipe casing is sunk by means of a heavy hammer or weight, operated from a frame or tripod and raised either by hand or machine; it is allowed to fall on the end of the pipe, within which there is another pipe to which a hose is attached and connected with a powerful force pump. At the bottom of this inner pipe is an expansion drill point which cuts away the material below the casing. This material, stirred up and held in suspension by the water jet, flows out with the water through a side outlet at the top of the casing pipe, as shown in Fig. 3, from "Water Supply Paper No. 257," U. S. Geological Survey.

By collecting portions of this water in a tub, a sample of the eroded material may be obtained. A record of the depth at which the drill was operating at the time the sample was taken should be made. In this manner a fair idea of the materials encountered may be obtained, although frequently it is difficult to distinguish between such similar deposits as the conglomerates and stiff and compact gravel. This may prove serious because the expense of excavating the one is far greater than the other.

In the report of the Burr-Hering-Freeman "Commission on Additional Water Supply for the City of New York" (1903, page 629) may be found a description of the method adopted in determining the location of ground water and the character of substrata as affecting the quantity, percolation and velocity of ground-water flow, from which report the following has been abstracted:

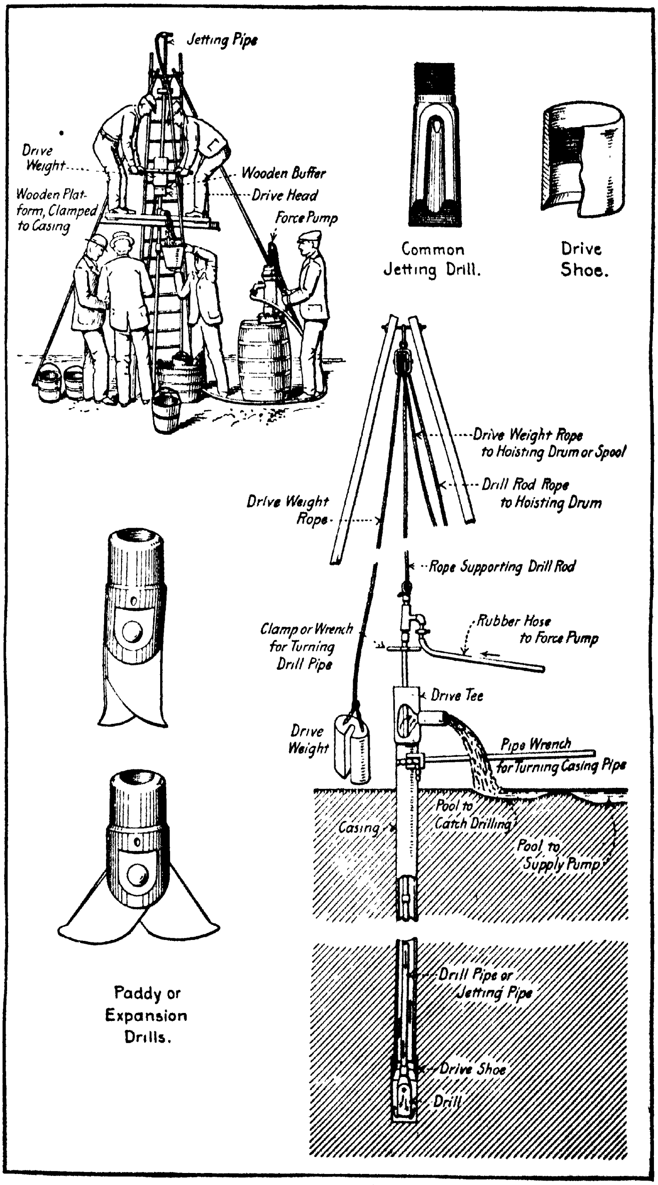
Jetting Pipe
Drive Weight
Wooden Platform, Clamped to Casing
Wooden Buffer
Drive Head
Force Pump
Common Jetting Drill.
Drive Shoe.
Drive Weight Rope to Hoisting Drum or Spool
Drill Rod Rope to Hoisting Drum
Drive Weight Rope
Rope Supporting Drill Rod
Clamp or Wrench for Turning Drill Pipe
Rubber Hose to Force Pump
Drive Tee
Drive Weight
Pipe Wrench for Turning Casing Pipe
Pool to Catch Drilling
Casing
Pool to Supply Pump
Drill Pipe or Jetting Pipe
Drive Shoe
Drill
Paddy or Expansion Drills.

Fig. 3.—A wash-boring outfit.

As these test wells were to be left in place for ground-water observations, economy in material was necessary and 2-in. wells were used.

The washed borings were to be made at intervals of several miles in a country for the most part devoid of surface streams, and at points necessarily at some distance from existing wells. The problems, then, were to devise an outfit of great portability, that could be operated with the least possible labor, and to haul to each outfit all the water that was required to drive the wells and secure good samples. The most serious of these problems was that of securing sufficient water for good washed samples. Throughout the work the necessary water was hauled to each outfit in barrels on the wagons that also served for the transportation of the outfit.

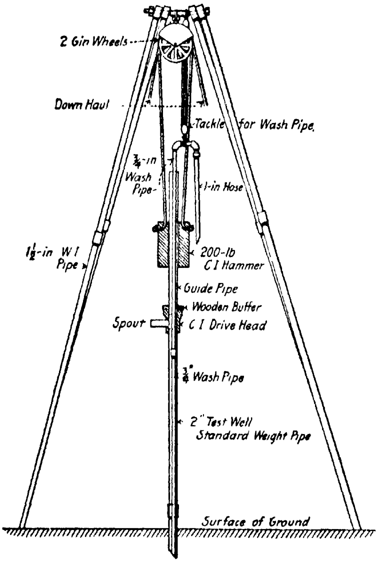

FIG. 4.—Wash-boring rig, New York Commission on Additional Water Supply.

The rig finally adopted for the test boring work of the Commission, Fig. 4, was patterned after a Boston rig. Two large gin wheels were suspended at the peak of a 1-1/2-in. pipe derrick about 12 ft. high, which served at the same time to carry a staging for handling the wash pipe, drive head and hammer. The great width of these gin wheels permitted the use of 1-in. ropes and the great diameter resulted in less frictional resistance; the height of the gin wheels allowed the men on the hammer to sway out on the lines instead of obliging them to double up on the last few feet of a length of casing, as with the Boston rig. With the stiff pipe derrick, it was also possible to secure core samples by driving 1-1/4-in. pipe 3 or 4 ft. into the material at the bottom of the casing. The drive-head, hammer, pump, suction and discharge hose and the wash pipe that were used with the Boston rig were retained. A force of four men and driver were employed with this outfit. The cost of this rig complete was about $150.

The engineering inspector assigned to each test boring outfit located the wells and, through the foreman, directed the work of driving. In addition to these duties, the inspector measured up the pipe that was driven, classified the samples and took all notes that were required. On the completion of each well, these notes were sent to the office on specially printed blanks.

Samples of the substrata were taken at all wells unless closed end points were used or unless a number of wells were grouped together, when samples from only one well were preserved. At each test well from which a knowledge of the material was required, dry samples of the soil and the subsoil immediately below were secured, and washed samples of the deeper substrata were taken every 5 ft. below the surface of the ground and at any change of material between those intervals.

When the inspector directed a washed sample to be taken, the entire discharge from the casing was caught in a large pail or tub of 8 to 15 gal. capacity, which was not allowed to overflow. The tub containing the sample was set aside for 15 to 30 minutes, after adding 2 c.c. of hydrochloric acid to hasten the precipitation of the fine material. When most of this had settled, the slightly turbid water was poured off and a sufficient amount of the material to fill the sample bottle was removed from the tub and the bottle was properly labeled and packed in the sample case provided for the purpose. The turbidity of the water that was poured off was observed and recorded in order to have a measure of the material lost.

It was hoped, at the beginning of the work, that it would be possible to use nothing but clear water in washing up the samples, but the distances over which it was generally necessary to haul the water and the large amount that was sometimes lost in driving through the coarse sands and gravels, made it necessary to use, on many wells, water containing considerable fine material; a limit to the turbidity of the water was fixed, however, and any water having a turbidity exceeding 200 on the silica standard was thrown away. In all the washed samples, the amount of fine material obtained did not, therefore, represent the actual quantity in the sample when in place, because of the rejection of turbid water from the sampling tub and the occasional use of turbid water for jetting.

The washed samples taken from the wells on which perforated pipe or open-end well points were used and those that were washed up with the small "house lift" pumps were not always as satisfactory as the others, because when washing through a mixture of gravel and sand the amount of water that returned to the surface was not sufficient in volume or velocity to readily bring up the coarse material. This was left in place after the sand in the mixture had been removed, and could sometimes be washed up only with great difficulty.

In many wells entire samples were obtained with an open-end or choke bore pipe, or a sand bucket, to serve as a check on the washed samples when the character of the material was such that the washed sample did not appear to be correct.

The plan of the work was to first fill in the large areas in which no existing wells were found by driving wells 4 to 5 miles apart; later, to locate other test wells at intervals of a mile or two, so that, with the existing wells, the surface of the ground water could be everywhere determined and accurately contoured.

An estimate of the total cost of the test boring, including the cost of inspection and supervision, and all other expenses incurred in the field and office on this work, is shown in Table 1 under the several items into which the cost may be divided.

TABLE 1.—COST OF TEST BORING

(Commission on Additional Water Supply for the City of New York)

Item	Total amount	Cost per foot of pipe driven (11,605 ft)
Superintendence and inspection (including engineering and supervision).	$2,815 36	$0.243
Labor—foremen, $3 and $3.50 per day; laborers, $1.50 and $1.75 per day	5,074.30	0 437
Teams employed with outfits, $3 and $3.50 per day	1,612 20	0.139
Transportation, car fare, livery, freight and express	559.73	0 048
Cost of rental of test boring rigs. .	618 43	0 053
Two-inch pipe, perforated pipe and joints	1,723 90	0 149
Misc. expenses, sample bottles, cases, classifying material, blasting, etc . . .	315 02	0 027
Total	$12,718.94	$1 096

In loose gravels the cost of the boring was not far from 60 cents per foot, but in compact till where dynamite was used, the cost ran up to $2 per foot, and some wells even higher.

To make the total cost per foot comparable with other work of this character which, however, has usually been confined to much smaller areas, the items of inspection, superintendence, pipe and fittings must be reduced, and the greater part of the item for teams taken out; for it is not generally customary to place more than one engineering inspector on several outfits, if any at all be assigned; the casings are usually pulled up, and the pipe used repeatedly; and water can ordinarily be piped to the work from a town supply, or from a small temporary pumping plant. If, then, we take 15 cents per foot from the item of inspection, 10 cents per foot from that of teams, and 10 cents per foot from the cost of the pipe, we reduce the total cost per foot to 75 cents. Considering the cost of labor, which was paid at the rate of $1.75, excepting during the first few weeks, and also the quality of labor that it was necessary to employ, this is a reasonable figure for the work.

In Fig. 5 is shown a combination drill and sand pump used by the city of Rochester, N. Y., in sounding along the line of a proposed outfall sewer in the bottom of Lake Ontario. N. A. Brown, Assistant City Engineer, who was in charge of this work, furnished the following description:

"To determine the material through which the trench will be dredged for the outlet pipe of the Rochester sewage disposal plant, borings were made in the bottom of Lake Ontario from the shore to a point 8400 ft. therefrom in August, 1909. A scow 10 ft. wide and 30 ft. long, having a 3 × 3-ft.

well in the center, was used for this work. Over this well a single block was placed at the head of a 12-ft. tripod to raise and lower the drill and handle the casing.

"A 2-in. pipe casing was used with a 1-in. pipe for a drill rod. At the bottom of the drill rod a combined sand pump and drill was attached. By means of holes in the casing, water was admitted to the casing and circulated through the sand and out the drill rod through a T at the top. Four holes were made on shore and 26 made in the water. The depth of water at the last hole was 61 ft. Of the 372.5 ft. of borings, 279 was sand, 88 was clay and 5.5 was gravel.

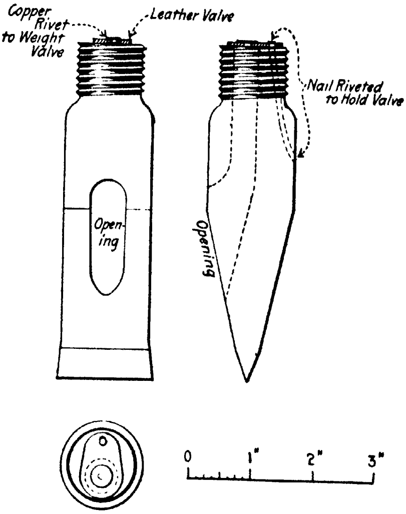

FIG. 5.—Drill and sand pump, Rochester.

"The following data give the cost of the drilling.

Equipment, including rigging scow, ropes and anchors, pipe, etc.	$114.89
Rental of scow and launch	139.00
Labor·	
2 drillers at $4.00 per day	
1 helper at $2.50 per day	142.85
Supervision	250.00
	$646.74

Total length of hole drilled	372.5 ft.
Cost per foot	$1.74
Average depth of hole	12.4 ft.
Cost per hole	$21.56

Average number of holes per day, not including the days lost because of unfavorable weather, 3.

Average number of holes per day, including those lost because of the weather, 2 1/2.

"The time required to lower casing, do the drilling and to remove the casing was 26 hours and 10 minutes to drill 226.4 ft. of sand and 54.1 ft. of clay. This gives an average of 1 ft. of hole every 6 minutes. Much time was required to move the scow and anchor it in position. All work was done 2 miles from the harbor so that no drilling was done any day before 10 o'clock."

In Fig. 6 is shown part of a profile of the bottom of Lake Ontario along the line of the proposed sewer outlet, which illustrates one way in which the results of borings may be indicated graphically.

In the larger part of Louisville, Ky., the soil consists of loam overlying fine yellow sand or clay, below which are sand and gravel. In the eastern section considerable ledge underlies the fine yellow sand and some sandy clay is found. The data given in Table 2 fairly represent the amount and cost of borings to furnish information relative to the character of materials to be encountered in excavating for the sewers built by the Commissioners of Sewerage.

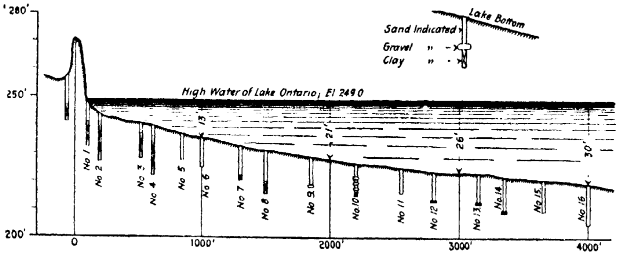

FIG 6 —Part of profile of site of Rochester outfall.

TABLE 2 —DATA RELATING TO BORINGS AT LOUISVILLE, KY.
(July-October, 1909)
(Report of Commissioners of Sewerage, Louisville, Ky., January, 1907, January, 1910)

Month	Feet	Cost per foot (cents)	Average depth of holes (feet)	Remarks
July.	1,274 5	6 1	19 6	Light augers
August	267 2	9 6	21 5	Light augers
September	157 0	7 7	21 7	Light augers
October.	223 5	17 9	24 8	Light augers
October.	161 1	21 3	20 1	Cased
October.	126 2	11 5	12 6	Light augers
Totals........	2,209 5	9 2	19.9	....

Core Drilling.—This method of drilling has the advantage that an exact sample of the material through which the well is driven is obtained, and may be preserved to show the exact nature of the soil or rock. Of the various core drills the most common types are the diamond drill and the shot drill. One form of diamond drill is described by its makers, the Sullivan Machinery Co., as follows:

> "The diamond drill consists of a line of hollow rods screwed together in 5 or 10-ft. sections, rotated by an engine through a shaft and gearing, and fed forward by either a hydraulic piston or by a screw feed At the lower end of the rods is placed a bit, in which pieces of 'black diamond' or carbon are set, and which, as the rods are rotated, cuts an annular hole in the rock, leaving a center pipe or 'core' undisturbed. Water is forced through the rods to keep the diamonds cool and to wash away the cuttings from the bit The essential feature of this method is the core or section of rock, which is formed by the hollow bit and rod as the drill advances. At intervals, usually after drilling 10 ft, the rods are withdrawn by means of hoisting mechanism, bringing with them the rock core, which is caught and held by a self-locking 'core-lifter' The core is then removed, the rods again lowered, and the process repeated until the desired depth is reached"

The shot drills are operated in much the same way as are the diamond drills, but in place of the diamonds in the cutting edge, hard chilled steel shot, which are fed into the bottom of the hole through the wash-water pipe, work their way beneath the cutting edge and become crushed and embedded into the softer steel of which the cutting edge is composed. The process is described by the McKiernan-Terry Drill Co., makers of such drills, as follows:

> "The actual cutting, however, is caused by the breaking of the shot, which, being of chilled steel and very hard, imbeds itself in the softer material of which the bit is composed. This action produces hundreds of minute pockets or cavities into which these small particles of shot are constantly caught and dropped, each time presenting a new facet which mills away the rock. This action keeps up until the shot particles become so small—practically powder—that the flow of water forces it up the bore hole above the drilling tools, at which point the water pressure is diminished, and it falls back and settles in the sludge receiver, together with the ascending detritus. When working properly the cutting edge of the bit will assume a half-round form, which keeps some of the shot off the bottom of the hole, and so produces for itself a sufficient space for clearance, both inside and outside of the bit."

Core drills have the added advantage that they may be operated through water as well as through the earth, thus permitting samples to be obtained from the bed of a river, lake, or other body of water. These devices are available for operation either by hand or horse power, and by belt or gearing from gasoline, oil, or steam engines, compressed air or electric motors.

The cost of diamond core drilling varies within wide limits, depending not alone on differences in the formation encountered, but also on labor, fuel, water, availability of supplies, living expenses, etc.

The Sullivan Machinery Co. gives the following costs:

> "A careful record of the cost of drilling, kept by a Michigan iron mining company which uses a number of diamond drills, shows total drilling costs (including carbon) ranging from $1.50 to $2.00 per foot. A large Western coal mining concern places the cost of its extensive diamond drilling operations at $1 per foot or less. A large number of holes, bored in the Lake Superior iron country and aggregating over 11,000 ft., showed costs ranging from $1.63 to $2.65 per foot. The cost of carbon in the former item was 19 cents and in the latter $1 per foot, the remainder being due to labor, fuel, superintendence, supplies, etc. A Mexican copper mine reports the cost of 4160 ft. of diamond drilling as $2.22 per foot, of which $1.03 was due to carbon wear. Eleven hundred feet of drilling in the copper formation of southeastern Arizona cost 38 cents a foot for carbon, and $1.35 for labor and all other items. The expense of long-continued coal prospecting in various states is reported as follows: Colorado, $1.65 per foot; Tennessee, $1.26; Indian Territory, $1.18; West Virginia, $1.13 to $1.50.
>
> "A recent compilation of statistics with reference to the cost of diamond drilling goes to show how variable is the cost of such work, and how utterly impossible it is to fix anything more than general rules from which an approximate figure of cost can be deduced. Out of 20 holes drilled through jasper, marble and iron slate, and varying in depth from 110 to 1100 ft., the average cost was $3.14 per foot. Of this cost, 39 per cent. went for labor, 22 per cent. for carbon and the remainder for fuel, repairs, supplies, etc. Another series of 16 holes, varying in depth from 94 to 380 ft., with an average of 314 ft., showed an average cost of $2.70 per foot. Of this amount 38 per cent. went for labor, and 13 per cent. for diamonds. The cost of drilling in soft schist rock was as low as $1 per foot, of which labor formed 66 per cent. and diamonds 30 per cent. The cost of drilling in hard syenite rock was twice that of drilling in tough diorite; the cost of the diamonds in drilling the syenite rock approximated 63 per cent. and the labor 38 per cent.; in the diorite rock the carbon cost 30 per cent., and the labor 66 per cent. of the total. The speed of drilling varied from 6 to 25 ft. per day, and the holes had a mean diameter of 1-3/4 in."

Frequency of Borings.—The frequency with which borings are made depends on the existing conditions, the requirements of the work in hand, and, in some cases, on the relative cost of excavation in different classes of material. For deep sewers laid in open cut, soundings or borings need be made no more frequently than is sufficient to show the approximate location and kinds of the several classes of excavation. If in tunnel work the grade to be established is dependent on the materials encountered, then borings must be made with sufficient frequency to furnish information for the preparation of a complete and accurate geological profile. If the grade is already established, then only sufficient borings are required to enable the engineer to determine the feasibility of the location and the approximate quantities of each of the several different classifications of material to be excavated.

In taking notes of soundings and borings, it is necessary to make an accurate description of the location of the test hole, to state the method used, to record the elevation of the surface of the ground at the point and the depth at which each class of material is encountered, giving a description of the character of each material. For each hole an accurate record of the cost of drilling should be made.

These records should be made at the time the work is performed, and later should be copied into the official record, and likewise be plotted upon the profiles, each classification of material being noted by characteristic and conventional marks, so that each classification may be quickly and readily recognized, as was done in the Rochester profile, Fig. 6.

Surface Conditions.—Record should be made of the extent and character of all impervious areas. It is desirable, when practicable, to obtain the areas of the street pavements, noted under their several classifications, such as asphalt, brick, granite block, wooden block, and macadam pavements; the areas of sidewalks, classified according to their several kinds; and the areas of roofs, yards, and passage-ways. These should be recorded in such a way as to make possible their ultimate classification by sewerage districts.

Investigation should be made to determine the approximate level of the ground water at different times.

The location of all outlets and points of discharge of all public and private sewers and drains should be carefully recorded, the sizes of pipe noted, and memoranda of the amount and character of the effluents should be kept.

The daily quantity of sewage discharged from the important sewers and drains under wet-season, dry-season, and mean-flow conditions should be determined, and the hourly variations in rate of flow should be noted, especially in the case of those sewers which carry industrial wastes.

Samples of river water above, within, and below the city should be taken and analyzed during the season at several stages of the river level, and particularly at the low-water stage.

Investigation should be made of the condition and use of the river above and below the city. This should include investigation of any litigation due to contamination of the river water.

Records of population should be obtained for as long a period as they exist, and estimates of the density of population should be made at the time of the investigation, such density to be estimated separately for each of the several sewer districts into which the community will ultimately be divided. This subject is discussed more fully in Volume I.

The record of water consumed may be obtained from the water department or company. Such information should cover the maximum, minimum and mean daily total and per capita consumption during each month, and the annual average consumption for a number of years previous to the time of the investigations.

The importance of compiling all available data relating to rainfall was discussed in several chapters of Volume I. While records showing the daily, monthly and annual precipitation should be made available for use in the study of certain problems, it is much more important to secure records of intensity of precipitation, as it is this rather than the total quantity which governs the sizes of the storm-sewers or drains. Such records covering a number of years are now available at many stations of the U. S. Weather Bureau. Occasionally valuable precipitation records have been kept by private parties.

Materials and Labor.—In order to be prepared to make close estimates of the cost of the proposed work, information should be gathered as to the prevailing prices upon all classes of material to be used in the work. Such cost should include, where possible, not only the price of the material and the freight charges, but also the cost of distribution to the several parts of the city where such materials will be delivered. Prices should be obtained upon cement, crushed stone, screened gravel, sand, sewer brick, vitrified sewer pipe and specials, light-weight cast-iron water pipe, lumber, manhole and catch-basin frames and covers, inlets, steel reinforcement of various types, coal and wood, loam, various classes of labor, foremen, sub-foremen, brickmasons and tenders, stonemasons, carpenters, blacksmiths, engineers and firemen, mechanics, bracers and semi-mechanics, unskilled labor, and single and double teams including driver.

OFFICE WORK PRELIMINARY TO DESIGN

Without waiting for the completion of the preliminary field work, it is desirable to organize the drafting department and begin the plotting of maps and profiles, so that even before the field work is completed many of the maps may be ready for the studies preliminary to design.

In plotting the surveys of city streets together with their structures, both surface and underground, the scale to be adopted will depend upon the conditions involved in each problem. In general, it is possible to show by characteristic lines all of the structures in sufficient detail on a map drawn to a scale of 1 in. to 200 ft. In some of the closely built

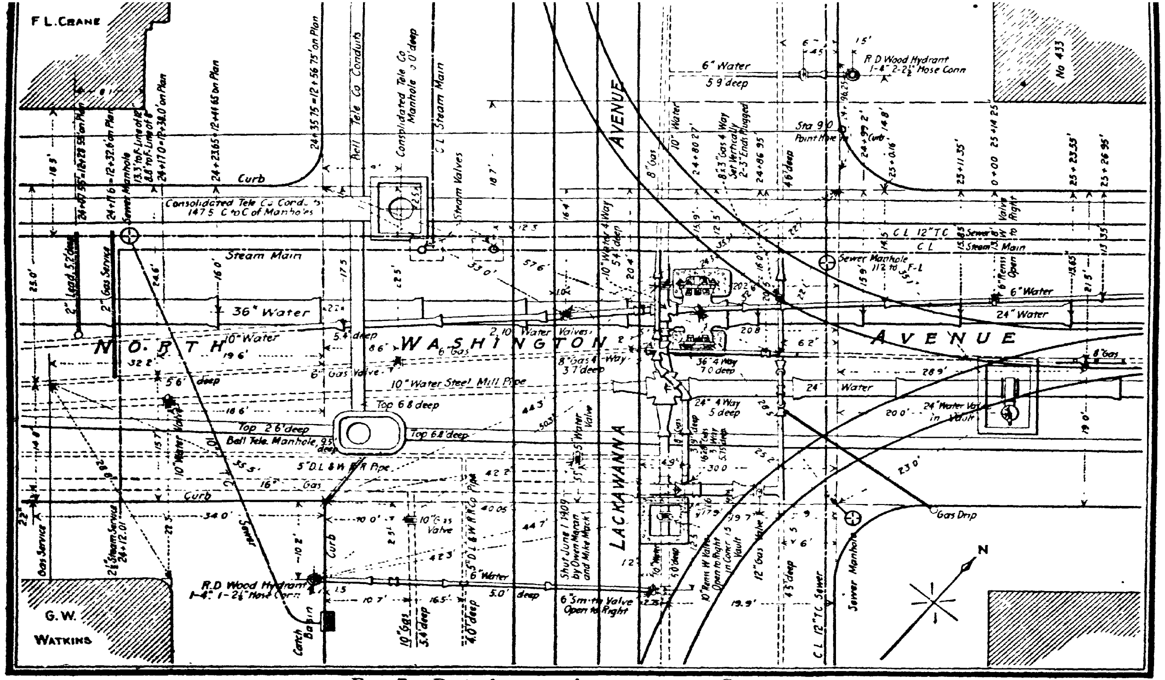

Fig. 7.—Part of street substructure map, Scranton.
(The original map is a little more than twice the size of this reproduction.)

up cities, with numerous pipes, conduits, etc., laid at random, it may be necessary to make such a map on a scale of 1 in. to 100 ft. Fig. 7 is reduced from such a map of Scranton. In either case, except for very small cities, it will be necessary to divide such a map into several sheets, in which case it is desirable to have all sheets of the same size, having a general or key map drawn to a smaller scale, say 1 in. to 1000 ft., on which are indicated the areas covered by the individual sheets. In some Western cities with rectangular street systems the maps of subsurface work have the street widths considerably exaggerated, and where details at street intersections must be shown to scale these are placed inside one of the blocks.

On such maps should be plotted all of the information which has been determined by the surveys, such as the street lines, car tracks, water, gas and sewer pipes, conduits for telephone, telegraph, electric light and heating, together with all manholes, gate-boxes, catch-basins, and other buried structures. The names of all streets, parks, public buildings, railroads, and water-courses should be noted and the points of compass shown by the plotting of a needle indicating true or magnetic north, as the case may be.

In determining the weight of the lines and lettering, due regard must be paid to the ultimate reduction which will be made in reproducing the map, if for publication, so that the lettering and lines may be well proportioned after the reduction has been made.

If possible, it is desirable to have the maps reduced by an amount such as to give an even scale, such as 1 in. to 500, 800, or 1000 ft., depending upon the amount of detail shown and the size of the maps desired.

If the map is to be photo-reduced it will be necessary to use colors which can be reproduced by that method. Blue reproduces very poorly, but if a little red is put in sepia the latter will come out fairly if the work is done by a good photographer.

The scale to be adopted for topographic maps will depend in great measure upon the amount of detail to be shown and the area covered. On a scale of 1000 ft. to the inch, it is possible to plot contours taken at 5-ft. intervals in rolling country, although in a hilly or mountainous country it would be necessary to adopt a larger scale in order to show sufficient detail.

The topographic map of Cincinnati recently made under the direction of Henry M. Waite included an area of about 102 square miles. It comprised about 48 sheets, the scale being 1 in. to 400 ft. and the contour intervals being 2-1/2 ft. on slopes of 6 deg. or less, 5 ft. on slopes of from 6 to 12 deg. and 10 ft. on slopes of more than 12 deg. Each sheet covers an area 8000 × 11,000 ft., the engraved portion being 20 × 27.5 in. About 150 miles of precise levels were run in connection with this work and 217 bench marks were set. The approximate cost of this map is given in Table 3.

TABLE 3.—APPROXIMATE COST OF TOPOGRAPHIC MAP OF CINCINNATI

	Total	Per sq. mi.	Per cent.
Triangulation	$5,326	$52.20	7.27
Precise levels	5,650	55.40	7.72
Traverse, plane table and mapping	38,242	374.90	52.25
Reproduction (200 copies)	19,145	187.70	26.15
Office expenses	4,837	47 40	6 61
	$ 73,200	$717 60	100.00

In addition to the contours, which should be plotted in sepia, if practicable under the method of reproduction, the water-courses, swamps, etc., should all be shown, preferably in blue, while the artificial features, such as roads, boundary lines, buildings, and all lettering, should be done in black, the weight of lines being decided upon after giving due regard to the possibility of reduction in reproduction.

The maps which are to be used to show the proposed sewer system should not have all of the detail which has been plotted on the regular city maps. In fact, it is probable that none of this detail is required except possibly the street and steam railway tracks, thus giving ample space to plot the proposed sewers and their connections in a bold line. The detail maps, however, should be made and studied with considerable care in order to decide upon a suitable location for the proposed sewer in each street. Where possible, it is desirable to have the entire sewer map on one sheet, even though this may require the complete re-plotting of the map. If this is not practicable, then a tracing may be made from the city map, giving street and alley lines, railway tracks, water courses, parks, the important public buildings, and the magnetic needle; on this the proposed sewers can afterward be plotted.

Profiles.—Profiles of each street in which sewers are contemplated, either at the time or in the future, should be plotted.

The scale adopted for the profile will depend upon the profile paper used, and the detail to be shown. It is quite common to use Plate B profile paper with a vertical scale of 1 in. to 6 ft. and a horizontal scale of 1 in. to 40 ft.

In such a profile, in addition to the surface of the ground, there should be shown an approximate profile of the ledge to be encountered, as determined from the borings which have been made, these borings being shown graphically on the profile to the depth to which each was taken, and the material through which the soundings were made being indicated by characteristic and conventional signs. All sewers and existing pipes, conduits, etc., which intersect the line of the sewer, should be shown at their true location and elevation on the profile. The names of all cross streets should be indicated, as well as the names of the streets through which the profile runs. The kinds of pavement to be excavated along the line of the sewer should be indicated, with arrows to show the limits of each class of pavement. The elevations of the inverts of all pipes and structures and of all deep cellars should be indicated.

Contract, Specifications and Drawings.—Contract drawings showing practically all details should be completed before contractors are requested to figure the work, thus giving them the benefit of a complete knowledge of exactly what structures are to be built and how they are designed. Such drawings should show, so far as practicable, all available information bearing upon the character of materials to be excavated, the location, size and character of structures likely to be encountered in the excavation, pavements, car tracks, etc.

The contract and specifications should be so drawn as to set forth clearly, and as completely as possible, all work, requirements and conditions included in or affecting the contract. While more time and expense will be involved in preparing drawings and writing contracts and specifications setting forth clearly all details and requirements, the net cost of the entire project will usually be materially less than if the drawings merely show in a general way what is to be done and the specifications are incomplete and obscure. Too much care cannot be used in this part of contract work, and much misunderstanding and difference of opinion between contractors, owners and engineers can be avoided if this part of the work is thoroughly and well done.

ORGANIZATION OF ENGINEERING DEPARTMENT FOR CONSTRUCTION

No hard and fast rule can be given for the organization of this department, which must be such as to meet the requirements of the specific work in hand. The organization must have structure and a definite plan. It must have a well-defined line of authority, and individual and departmental responsibility must be so clearly defined that it may be thoroughly appreciated by each individual in the organization. To this end the work within each division or department must be clearly outlined, so that there may be no doubt as to the field embraced thereby. The work must be systematized, and a thorough system of accounting established, so that the cost of running each department may be clearly shown. Above all, there must be good esprit de corps, cordial co-operation and good discipline. Toward this end weekly joint meetings or conferences between the chief and division engineers at headquarters and occasional visits to the different branches of the work are very desirable.

The size and plan of organization will depend largely upon the size of

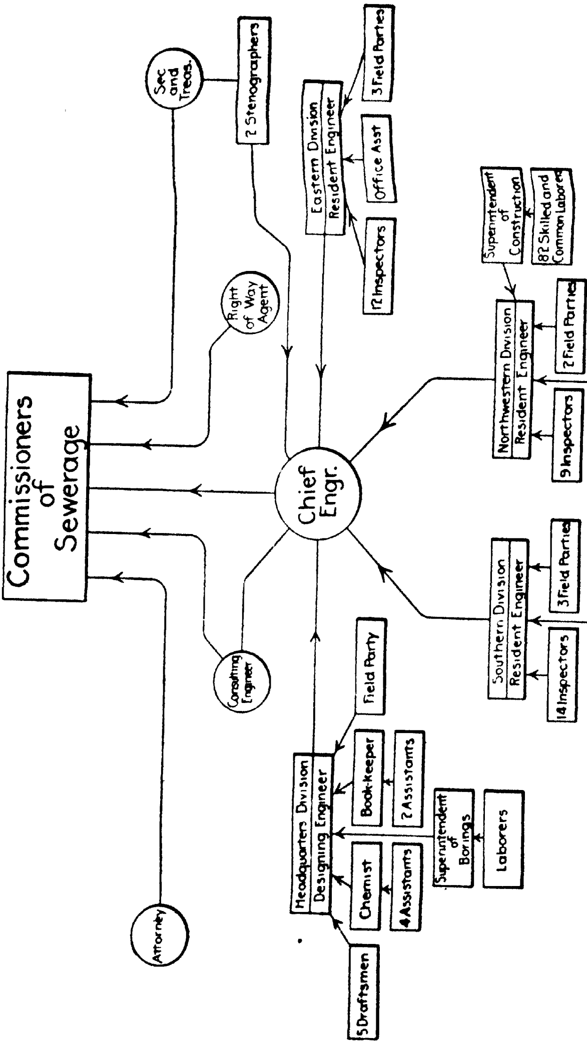

FIG. 8.—Organization of staff, Commissioners of Sewerage, Louisville.

the undertaking. An example which may be helpful to engineers about to form such an organization is that of the Commissioners of Sewerage of Louisville, Ky., Fig. 8. In this organization the work was under the direction of a sewerage commission; the engineering work was in the charge of a chief engineer, who, together with his consulting engineer, reported directly to the commission and was responsible for the work of the entire engineering department. The several departmental engineers, one of whom was in charge of the headquarters and design division and the others of different divisions of the construction work, all reported to the chief engineer.

The headquarters division engineer had control of the drafting department, the laboratory, the accounting and bookkeeping department, and the department having charge of the test pits and borings. It is often advisable for him to have charge also of the preliminary field surveys.

Each of the resident or division engineers had an office assistant who had charge of the records of the division, and several field parties, each with an assistant engineer in charge, and also a force of inspectors in charge of the inspection of respective sections of the construction work.

In the organization here shown the stenographic force served the engineering department as well as the commissioners, and although their duties were apparently divided they were directly responsible to the chief engineer, whose work occupied the greater portion of their time.

CHAPTER II

ENGINEERING WORK AND INSPECTION DURING CONSTRUCTION

Laying Out Trench Work.—There are a number of different methods in use for staking out trenches for sewer construction. In undeveloped country stakes may be driven on the center line of the sewer at 50-ft. intervals, from which the line of the excavation may be marked off on either side, after which the stakes are removed as the excavation proceeds.

A similar method may be used in city streets, except that in place of the stakes large spikes are driven into the pavement. In order that these spikes may be readily found a small piece of heavy canvas about 4 in. square may be placed on the ground and the spike driven through it, thus pinning the canvas to the surface of the street.

Stakes or spikes, according as the sewer may be in undeveloped or developed territory, may be driven on a line parallel to and offset a few feet from the center line, at 50-ft. intervals. In choosing the side on which these offset stakes or spikes should be driven, due consideration must be given to the side of the trench on which the excavated earth will probably be thrown out, the stakes being placed upon the opposite side.

If it is possible to have an instrument man on the work at all times, stakes or spikes at the center of each manhole will be sufficient. In this case the line for the opening of each piece of trench may be given directly by means of the instrument.

Reference Marks.—In staking out sewer trench, the line should be so referenced that it may be readily and quickly located at the time of construction. Several methods are used for this purpose:

1. The center of each manhole, where the sewer is straight between manholes, may be referenced by means of "cross references" intersecting at the center. These reference points must be such that they will not be disturbed and yet may be easily re-located and readily used. It should be possible to set the transit over one point in each pair of references in case it becomes necessary to use the transit in finding or re-locating the center point. In replacing a center point which has been disturbed it may not be necessary to set the instrument on each pair of references, if these reference points have been so located that a string may be stretched between each pair. In this case the intersection of the two strings determines the center of the manhole.

2. Points on the center line of the sewer, including the centers of all manholes, may each be located by two or more ties taken with a steel tape from nails driven into trees, posts, or fences, each properly described so as to be readily found. In making such ties originally, it may be well to hang the ring of the tape on the nail so that the ties may be used by one person without assistance.

Transferring Line to the Sewer.—If the offset method of staking out sewers has been adopted, it is possible to locate a stake in the bottom of the trench as it nears completion by measuring the offset from the offset stake. This method is not recommended, however, inasmuch as caving of the banks may disturb the offset stake and the use of bottom stakes is not convenient.

A more acceptable method of determining the sewer line is by means of "batter boards" located, as shown in Fig. 9, at 25-ft. intervals.

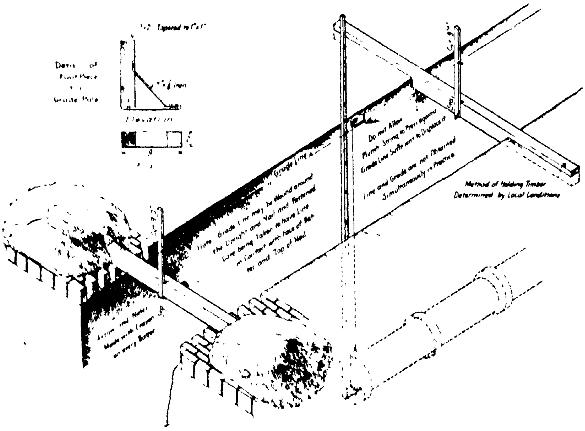
Tapered to 1"x1"
Detail of Foot Piece for Grade Pole
Elevation
Grade Line
Note: Grade Line may be Wound around the Upright and Nail and Fastened, Care being Taken to have Line in Contact with Face of Batter and Top of Nail
Do not Allow Plumb String to Press against Grade Line Sufficient to Displace it
Line and Grade are not Obtained Simultaneously in Practice
Method of Holding Timber Determined by Local Conditions
Made with Crayon on every Batter

FIG. 9.—Giving line and grade for pipe sewers.

The method of erecting these "batter boards" is as follows: 2 × 8-in. planks are selected, about 7 or 8 ft. longer than the top width of the trench. These planks are set up edgewise across the trench every 25 ft. and sunk into the surface of the ground on either side of the trench to a depth of 5 in. or more, and held securely in position by tamping earth solidly about them. In paved streets, rather than to cut into the pavements outside of the trench lines, these planks, or preferably 4 × 6-in. or 6 × 6-in. timbers, may be set on the pavement and weighted down with compact earth or paving stones.

When a number of these cross pieces are in place, a transit is set up at the nearest transit point, and after obtaining line, a nail is driven on the true center line in the top of each of these cross pieces and close to one (uniformly the same) edge of it. Pieces of 3 × 1-in. batten, dressed all around and about 3 ft. long, are then nailed securely to these cross pieces, with one edge (uniformly the same) placed on line as determined from the nails above referred to, and are plumbed by means of a carpenter's hand level or a plumb string.

The level party then establishes a grade upon these battens at a given distance above the invert of the sewer and drives a finishing nail (nail without a head) horizontally into the batten. These nails should be driven into the "line face" of the batten, and the distance which these nails are above the invert of the sewer should be clearly marked on the face of the batten. A stout cord is then fastened around the batten and drawn up over the nail, at the same time resting against the "line face" of the batten. This cord is then run to the nearest batten, drawn tightly over its nail, and wound around the batten, and if it is desired to continue the line over a longer stretch of trench, the cord is then run ahead to the next batten, and so on until at the last batten the string is firmly fastened. If the battens have been properly set, and nails accurately driven, and the cord carefully adjusted, making sure that it passes over the nail and close to the batten in each case, it will, therefore, be parallel to the invert and vertically over the center line of the sewer.

Checking.—The alignment of the battens should be checked by eye immediately following their setting, to detect errors, such as the setting of the wrong edge of the batten to line, etc. The alignment may be conveniently checked by sighting several battens with the naked eye, and in doing this care must be taken each time to allow the sight to include two or more battens that have previously been checked, so as to detect a sudden break in the line.

It is not sufficient merely to check these lines at the outset, but the inspector should cast his eye along the battens frequently during each day, and if the trench has any tendency to settle or if there is opportunity for the batter boards to be disturbed, these lines should be checked by instrument at frequent intervals, possibly daily.

Grades.—As previously stated, it is desirable to have well-defined and accurate bench marks established at frequent intervals, so that the instrument man may obtain the height of his instrument directly from a well-established bench at any point along the sewer trench where he may desire a "set-up." Having determined the height of instrument from such a bench, it is desirable to check that height of instrument before any grades are given by a sight upon a second bench mark, if one is available. In the absence of a second convenient bench mark it is desirable to establish a turning point in the direction of the next adjacent bench mark. After all the grades have been given from the one set-up, the second bench or the temporary turning point should be carefully checked to satisfy the instrument man that his level has not been disturbed. Where the turning point has been used a secondary set-up should then be made to check this work with the next bench mark.

In driving nails in the line face of the batten, preferably at even feet above the sewer invert, the exact position of this nail should be determined by the rodman by holding his rod against the face of the batten and at the same time holding the blade of his knife at the base of the rod ready to insert the point of the blade into the batten when the levelman signifies the correctness of the position. The nail is then driven so that its top will be level with this cut mark. After the nail has been driven, the rodman should hold his rod upon the top of the nail for the levelman's check. As soon as the nail is established, the rodman should mark upon the face of the batten the distance which the nail is above the invert.

A more convenient method under some conditions is to hold the rod on the cross piece at the line nail, securing its elevation and computing therefrom the distance above or below the cross piece at which the nail should be driven. This distance may be measured by a rule and the nail driven accordingly.

Still another method is to measure off the proper distance on the batten and mark it with a pencil line across the stick. The batten is then nailed to the cross piece so that the pencil line will coincide with the top of the cross piece. The cord is then drawn over the top of the batten, the center of which is over the center line of the sewer. This is probably the quickest method and in the hands of careful engineers has given entirely satisfactory results.

When the cord is tightly drawn over these nails from batten to batten, the string then being parallel to and at a stated distance above the invert of the sewer, the grade is transferred therefrom to the invert by means of a graduated pole terminating in a shoe, shaped like a bracket, set at right angles to the pole in such a manner that when the base of the bracket is in the invert of the pipe and the pole held plumb, Fig. 9, the correct distance is established by raising or lowering the pipe until a mark on the pole agrees with the distance marked on the face of the batten.

After the pipe has been brought substantially to its true grade, its alignment is checked by means of a plumb-bob, suspended by a string held lightly against the stretched cord, so that the point of the plumb-bob rests immediately above the crown of the sewer pipe, the pipe being moved over until its center is immediately below the point of the plumb-bob.

The grade nails should be checked frequently, first immediately following the setting, and occasionally throughout the day by sighting over the tops of a half dozen or more to make sure that they also are in a common plane, care being taken to sight over at least two nails that have been previously and similarly checked.

Layout of Disposal Works and Other Structures.—All structures should be staked out in a manner that will permit placing reference marks which will remain permanent and accessible throughout the construction period. Many of these reference points should permit setting a transit over them. The reference points should be sufficient in number so that as the structure grows there always may be several points from which the line of sight may be obtained.

In addition to these permanent reference marks and transit points, it is of great advantage, especially during the period of excavation, to make use of batter boards placed outside the line of excavation in a similar manner to those used by the house builder in excavating for and building house foundations. The posts for such batter boards should be firmly driven and the boards placed at a uniform elevation, corresponding with, or to a stated distance above or below, some important grade of the structure. The lines of the excavation may be established on these boards and nails driven in their tops, across which strings may be drawn to indicate such lines.

When a large area is to be excavated to one or more levels, these batter boards may be used for sighting, and the finished grade of excavation ascertained by a stick on which a cross stick is nailed at such an elevation above its bottom as corresponds with the elevation of the batter boards above the grade required. In this way a number of points about the area to be excavated may be "spotted" and the balance of the excavation brought to conform to these grades.

Where concrete or other masonry is to be placed directly upon the bottom of the excavation over a considerable area it is always wise to test such excavation, just prior to its completion, with a level and rod as a precaution to prevent unnecessary excavation and refill.

Lines and grades should be given by the instrument man directly on all forms for masonry as well as on all other structures when these are first placed, and such lines and grades should be frequently checked during the progress of the work.

Before the work is laid out a number of bench marks should be established at convenient points. The elevations of these bench marks should be accurately determined and the benches should be permanent, easily accessible, and well protected.

Where a river is to be crossed by a sewer and where outfalls are to be laid far out into a body of water, it is absolutely necessary to have the lines so referenced that they may be re-established accurately and quickly at any time.

Where possible to get a permanent foresight, a common method is to establish a transit point on or near the shore, at a point on the center line of the proposed structure, which can be readily occupied at any time during the progress of the work, either directly, before the excavation has been made, or by means of a platform during the progress of the work.

A range line is thus established between this point and the permanent foresight, which may be a prominent point on a building, such as a steeple or flag pole on the opposite shore, in the case of a river or small lake, or a target upon a bunch of piles driven beyond the limits of the outfall or intake in the lake or ocean, as the case may be.

To establish definite points on this range line, a second transit may be located at the other end of a base line established on the shore of the lake or the bank of the river, this base line being of such a length as to make the angles of intersection between the base line and the line of sight to the various points along the line of the structure larger than 45 deg., if possible.

The stadia may be used for locating points along the range line, provided it is possible to hold the stadia board reasonably quiet during the observation. This can be done where a sight is given from a heavy and substantial steam launch, raft, or scow, but is not practicable with the ordinary rowboat.

Another and very positive method of locating the center line of an outfall or intake is by means of batter boards upon pile bents driven solidly into the bottom of the body of water across the proposed line of the structure. The center line can be established on these batter boards and can be checked up frequently, the distances being measured directly, using extra long tapes where it seems necessary to make the spacing greater than the length of the ordinary steel tape. In this case floats should be provided to support this tape at intermediate points.

SUPERVISION AND INSPECTION

All construction work should receive careful supervision to insure securing structures conforming with the plans and requirements of the engineer. For this purpose it is customary to furnish the resident engineer one or more inspectors, whose duty it is to see that all work as laid out by the engineering department is faithfully and accurately executed.

It is the duty of the inspector to safeguard the permanency of all line and grade boards, reference marks, etc., and he should satisfy himself by frequent observations that such boards and points have not been disturbed, and if in doubt as to their accuracy at any time should call immediately upon the engineering force to re-test them.

The inspector should assure himself that all lines and grades furnished by the engineer on batter boards are accurately transferred to the structure. In sewer work the inspector may choose to perform this work first hand, giving the line by means of the plumb-bob and testing the grade by means of the grade pole as already described. Where the work is performed by contract, specifications usually require this work to be done by the contractor "to the satisfaction of the engineer," in which case the inspector may justly require the contractor to attend to the alignment and grading of the structure, the inspector satisfying himself by frequent tests as to the accuracy of the work.

All materials should be inspected upon delivery, and some should be again inspected when they are to be put into the work. The character of workmanship should be subject to constant inspection.

Pipe.—The inspection of vitrified pipe is described in Chapter XI. Cast-iron pipe should be inspected as unloaded from the car and again before lowering into the trench, special care being taken to note the appearance of cracks at the spigot end. A heavy cotton mitten or a bunch of dusty waste may be used to rub over the spigot, both outside and in, and if the pipe is cracked, the dust found on the pipe or contained in the waste when rubbed into the crack makes it more readily visible, as is the case with vitrified clay pipe. Cracked pipe may also be discovered by "sounding" with a wooden mallet while suspended or on the "rolls."

Cement.—Cement should be delivered sufficiently in advance of the time when it will be required for use to permit the tests required under the contract. The method of storing and tagging will depend upon the size of the work. Where only small quantities are being used and the cement is delivered by the dealer in wagon loads, the tagging should be done when it is unloaded from the cars into the dealer's storehouse. Provision should be made for setting aside that portion of the cement to be used upon the sewer work so that the dealer will not send it out for other construction. Under these conditions, it is usually necessary to place a tag on each bag of cement, for the storehouse is not likely to be under the eye of the inspector. He can be sure that the cement delivered has been tested only if each bag is tagged. Upon larger work, requiring a number of carloads of cement, where the contractor must provide a special storehouse for its protection, it will only be necessary to tag a relatively small number of bags, as one in every six or ten. Such storehouses are usually sufficiently close to the work so that the inspector may have a reasonable knowledge of the quantity of cement on hand and the portion which is being delivered. Where large quantities of cement are being used upon several different portions of the work, and the testing is done at a central laboratory, it will be found convenient to mail from the laboratory each evening postal cards designating the numbers of the carload lots of cement which have been released by the tests of the day, thus giving to the inspectors a record of released cement from which the contractor is entitled to draw.

Sand.—All sand should be inspected for its cleanliness and suitableness, and where the importance of the work justifies it, may be analyzed mechanically to make sure that it is of the proper proportions. Experience shows that some sands give good results with certain brands of cement and poor results with other equally good brands. On important hydraulic work some engineering firms now require cement to be tested with the sand to be used on the work, as they have had to change brands on important contracts because of this peculiarity. Taylor & Thompson, in the second edition of "Concrete, Plain and Reinforced," page 159, express the belief that "unless the sand is from a bank of known quality it is even more necessary to test the sand than to test the cement," and they refer to the tests recommended by the Joint Committee on Concrete and Reinforced Concrete in 1909, as follows:

> "Mortars composed of one part Portland cement and three parts fine aggregate, by weight, when made into briquettes should show a tensile strength of at least 70 per cent of the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand. To avoid the removal of any coating on the grains which may affect the strength, bank sands should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting weight. From 10 to 40 per cent. more water may be required in mixing bank or artificial sands than for standard Ottawa sand to produce the same consistency.
>
> "Since the relative strength of sand mortars, which are free from organic or other impurities, is governed by the sizes and relative sizes of the grains, mechanical analysis tests are recommended by the Reinforced Concrete Committee of the National Association of Cement Users, 1909, as frequently of great value in selecting a sand.
>
> "The relative strength of mortars from different sands is largely affected by the size of the grains. A coarse sand gives a stronger mortar than a fine one, and generally a gradation of grains from fine to coarse is advantageous. If a sand is so fine that more than 10 per cent. of the total dry weight passes a No. 100 sieve, that is, a sieve having 100 meshes to the linear inch, or if more than 35 per cent. of the total dry weight passes a sieve having 50 meshes to the linear inch, it should be rejected or used with a large excess of cement.
>
> "For the purpose of comparing the quality of different sands a test of the mechanical analysis or granulometric composition is recommended, although this should not be substituted for the strength test. The percentages of the total weight passing each sieve should be recorded. For this test the following sieves are recommended.[1]

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[1] Sheet brass perforated with round holes passes the material more quickly than square holes. Round holes corresponding to sieves No. 8, 20 and 50 respectively are approximately 0.125, 0.050, 0.020 in. diameter.

0.250 inch diameter holes[1]
No. 8 mesh, holes 0.0955 in. width, No. 23 wire
No. 20 mesh, holes 0.0335 in. width, No. 28 wire
No. 50 mesh, holes 0.0110 in. width, No. 35 wire
No. 100 mesh, holes 0.0055 in. width, No. 40 wire

"To determine the percentage of organic impurities, the silt can be removed from the sand by placing it in a large bottle and washing it with several waters. The wash water is evaporated, and the residue is screened through a No. 100 mesh sieve to remove coarse particles which do not affect the strength. The silt passing this sieve is weighed to obtain the percentage of the original sand, and then ignited in a platinum crucible to determine, after driving off the water, the percentage of combustible organic matter. Although data on the subject are incomplete, tests by Mr. Thompson tend to indicate that if the silt in a sand has more than 10 per cent. organic matter, and at the same time if the organic matter amounts to over 0.1 per cent. of the total sand, the use of the sand may be dangerous."[2]

Crushed stone and gravel should be inspected as to character, quality, and condition after the same general manner used for the sand. The character of the material, particularly with reference to its soundness and suitability for the work in hand, is of importance because there is a great difference in the character and hardness of the different stones. Particular care should be taken to obtain sound stone that has not weathered badly. The limestones may be distinguished from the quartzite and trap rocks by the use of hydrochloric acid, which produces effervescence when applied to the limestone. Care must be taken to have stone which is reasonably clean and free from dirt, in order that the cement may bond the stones securely.

It is desirable to make mechanical analyses of the aggregate from time to time in the same general manner as of sand, in order to get the densest and most economical mixture. The mechanical analysis of sand is described in Volume III.

Brick.—Brick should be examined to make sure that deliveries are in accordance with the contract, and that the brick are similar in hardness, size, shape, imperviousness, composition, color, etc., to the sample submitted. The brick should also be clean and free from any foreign coating which would prevent good bond with the mortar. In certain classes of work, absorption tests must be made to determine the porosity of the brick.

Reinforcing steel should be examined when delivered, to make sure that it conforms with the bill of materials, and the cross-sections of the different rods should be measured. It is desirable, of course, that the material should be received free from rust and mill scale, but absolute adherence to this requirement is difficult of attainment in practice and will involve substantial cost which is generally not warranted in view of the protective effect of mortar upon the steel. Any serious rusting or pitting of the material should, however, be sufficient cause for its rejection.

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[1] A No. 4 sieve, having 4 meshes per linear inch, passes approximately the same size grains as a sieve with 0.25 diameter holes

[2] See "Impurities in Sand for Concrete" by Sanford E. Thompson, *Trans. Am. Soc. C. E.*, 1909. The subject is also discussed in Chapter XIII under Mortar.

Miscellaneous.—Gates, valves, and other specials should be examined to make sure that the correct number of the various sizes as called for in the order are delivered, that they conform with the specifications, and that they have not been damaged in transit.

All other materials delivered for use in the work should be thoroughly examined to make sure that they are suited for the work required.

It is the inspector's duty to require and secure the quality of workmanship required by the contract. To this end he should satisfy himself that pipe inverts are smoothly laid and set to the proper grade; that joints are prepared as required by the contract; that all surplus jointing material is removed from the inside of the pipe as the work progresses; that water in the trench is kept below and from within the pipe until the joints are perfectly set; that concrete is mixed in proper proportions and of suitable consistency and placed in a satisfactory manner; that concrete forms are erected to the lines required, and so constructed as to secure a satisfactory surface and to prevent loss of water through imperfect joints.

Excavation.—Although inspectors often consider that excavation and backfilling require but little or no inspection, it is, on the contrary, very important that due attention be given to this branch of the work throughout the entire period of construction. In fact, carelessness in excavation or in backfilling may be the cause of great inconvenience and heavy financial loss, due to the settlement of the surrounding ground and the adjacent buildings, cracks in or deformation of the structure being built, and like troubles.

To prevent the occurrence of such settlement, it is very important that the inspector should be keen in his observations of the excavation to make sure that no unnecessary materials are excavated, either directly or indirectly, from outside the trench line; that the bracing of the trench is sufficient to prevent settlement, and that the sheeting is kept driven sufficiently in advance of the excavation to prevent inflow of materials at the side of the trench. Where quicksands are encountered, the greatest precautions should be taken to prevent boiling of the sand with its resulting tendency to cause settlement of the surrounding territory.

In this connection, when material is to be traversed of such a nature or under such conditions as to be likely to displacement or flow, which may cause serious or damaging settlement of adjacent structures, it is well to take photographs (which should be dated on the negatives) of the adjacent buildings and to take a sufficient number of elevations upon the buildings so that complete information may be had as to the condition of these buildings before and after the execution of the work. Such information may be of the greatest value in case of litigation.

Precautions should also be taken to prevent the excavation of material from below grade except where its inferior quality requires its removal and replacement with more suitable material

Backfilling.—Careful and faithful backfilling is of the utmost importance, although frequently seriously neglected. Where underdrains are laid beneath sewers, the inspector must see that they are properly laid and surrounded with screened gravel or crushed stone and that the refilling below subgrade is thoroughly done, that there may be no danger of settlement of the sewer.

Underdrains for filter beds may require special treatment, in which case the information in the specifications and drawings should be such as to afford the inspector, as well as the contractor, his instructions.

The material used in backfilling around pipe sewers should be fine and free from lumps, well tamped beneath and adjacent to the sides of the pipes, and in 4 to 6-in. layers until the pipe has been covered from 6 to 12 in. in depth, and where settlement of the surface is to be prevented, the remaining backfilling should also be placed in layers, each thoroughly tamped. If the material is dumped from a height exceeding 5 ft. above the top of the masonry or pipe its fall must be broken by a timber grillage or other means, so that no damage will occur to the structure.

If the backfilling around and beneath the pipe is not carefully and thoroughly placed, there is a tendency for the earth to settle away from the pipe and leave it without support, so that the weight of the superimposed earth may deform the pipe and cause ultimate failure.

Removal of Sheeting.—Sheeting driven below the springing line of a sewer should not be withdrawn unless absolutely necessary, as it is extremely difficult to fill the voids thus left, in which case the structure does not have the support it should from the banks of the trench.

If the sheeting is drawn after the trench has been backfilled, and especially if it has been driven below the springing line, care should be taken to fill the voids thoroughly so as to prevent the ultimate slumping of the earth already backfilled around the pipe. One way of accomplishing this is to withdraw the sheeting a little at a time, as the backfilling progresses, and to force some of the partly backfilled earth into the void thus left by the withdrawn sheeting by means of a water jet, consisting of a 1-in. garden hose terminating in a piece of 3/4-in. water pipe. This pipe nozzle can then be forced down through the backfilling and by moving it up and down the partly backfilled earth may be washed into the void, thus compactly filling it. This pipe, if of sufficient length, may be operated by a man on the surface without interruption of the backfilling.

Where it is considered that the backfill is liable to settle, it is not desirable to replace the paving in its final position until time has been allowed for this settlement. Consequently paving is frequently placed in a temporary manner, so as to permit the passing of teams and traffic with safety during the period of settlement.

Final Inspection.—Notwithstanding that the daily inspections may have been thorough and painstaking, a complete and systematic inspection of the entire work should be made before it is accepted.

The engineer should walk through the entire length of all large sewers, with a powerful lamp equipped with a good reflector, to observe critically their physical condition, cracks, abrasions, leaks or defects or weaknesses of any kind, and the presence of foreign substances, such as lumber, bricks, and débris.

In passing through tunnels, test should be made frequently by striking with a long and heavy bar for hollow sounds resulting from incomplete filling of the entire excavation outside of the tunnel lining. If any such points are found their location should be noted and marks should be placed directly upon the masonry to aid in re-location. Such voids should thereafter be completely filled with rich cement grout, by means of a powerful force pump.

All small sewers should be systematically inspected by means of light thrown in either by reflecting sunlight, powerful electric lamps with reflectors, acetylene lamps, or by means of floating lamps or candles.

If there appears to be considerable leakage into the sewer, it is well to measure it as accurately as practicable at a time when conditions are favorable to infiltration. At certain seasons of the year there may be little or no infiltration because the sewer lies above the surface of the ground water, while at other seasons it may be under considerable head and the quantity of leakage may be large. Under conditions favorable to infiltration an average leakage as low as 5000 gal. per day per mile of sewer may be considered to have reached the practical minimum, although if this quantity of water finds its way into the sewer at a single point or in a short length of sewer, the leakage may be considered excessive and the re-construction of the sewer at this point or locality may be warranted. The subject of leakage is discussed in Volume I, page 182.

It is difficult to fix upon the maximum quantity of leakage which should be permitted and beyond which the sewer must be repaired or re-laid. One principle to be borne in mind is that it is useless to tear up and re-build a sewer to prevent leakage if the conditions are such that there is a probability that the re-constructed sewer may leak as much as the one taken out. The time to prevent leakage is when the sewer is being built. If, however, in spite of the most careful work and rigid inspection, it develops that there are serious leaks in the sewer, those portions through which the water finds admission should be taken up and re-constructed, or the sewer may be encased in masonry if the leakage is localized.

Leakage.—By noting the increase in the rate of flow from manhole to manhole or section to section, it may be possible to locate the sections of the sewer furnishing the larger portions of the leakage. By damming the flow just above this section of the sewer by means of movable plugs, sand bags, or other devices it may be possible, by means of reflected light, to locate the source of leakage within the section. If such leakage is found to be local, the spot or spots should be excavated and the sewer or the house drain, as the case may be, should be repaired or re-laid.

In connection with the damming of such sewers for the purpose of inspection, care should be taken to make sure that neither the sand bags nor the plugs which may be used are forced into the sewer, lest the sewer be thus plugged in a manner which it may be very expensive to remedy.

The entire district in which sewers have been laid should be traversed, and the backfilling carefully inspected and notes taken of any pavements which should be replaced or trench which needs repair.

Relations of Engineers and Inspectors to the Contractor.—So many and varied conditions affect the relations existing between the engineers and inspectors and the contractor that no specific rules of conduct can be formulated which the engineers and inspectors can follow in all cases. The engineer is usually in the position of judge rather than advocate, and it is for him to interpret the contract fairly as between the sometimes conflicting interests of the two parties to the contract. This position is often a difficult one, requiring experience, a judicial temperament, self-control, tact and firmness.

Much difficulty may be avoided by carefully prepared contract, specifications and drawings showing the work to be done with accuracy and in detail, based upon a general scheme well thought out and studied in advance. Under ideal conditions, the contract, specifications and drawings will tell the contractor exactly what is to be done and he can base his bids upon a nearly complete knowledge, the only questions remaining being those raised by conditions which cannot be known in advance. Ideal specifications and drawings rarely if ever exist, but it should be the effort of the engineer to make his approach the ideal as closely as possible.

A spirit of active and friendly co-operation with the contractor should always be cultivated by members of the engineering corps in the interest of good and rapid construction. Under such conditions, good mutual respect is usually soon established, and if the questions arising in the interpretation of the contract are decided in the light of common sense and fair dealing, the work should proceed under harmonious and favorable conditions. It is the duty of engineers and inspectors to secure the quality of work required by the specifications, which quality should be defined in them as accurately as possible. As a rule, it is scarcely more expensive for the contractor to provide first-class workmanship than to do the work in a careless and slovenly manner. If this principle is recognized by the contractor, and his work is so planned as to be skillfully handled, much will have been accomplished to secure harmony between the engineering force and the builder of the sewer.

MEASUREMENTS AND ESTIMATES

Preliminary Measurements.—The necessary measurements depend largely upon the method of payment stipulated in the contract.

In trench work, if payments are to be made on the basis of "unit prices," a profile upon the center line, using stations in common with those used in laying out the work, should be made, and where ledge is encountered at an elevation above subgrade it must be profiled before being removed. These measurements are made the basis of payments, and must be accurately made and recorded.

Where the contract provides for payment on a "per linear foot of trench" basis, the above profiles are desirable for record, although not absolutely necessary.

For sewage treatment works and other structures, the surface for the entire area to be excavated should be cross-sectioned, together with all areas of ledge encountered at the start or during the progress of the work. All features calling for special payment under the contract should be measured up in advance of the work, such as the number of square yards in all pavements to be removed, the area and average depth of all top soil to be removed and reserved for future use, and the linear feet of piping to be taken up and re-laid.

All the pipes and other structures encountered by the excavation during the progress of the work should be carefully located and a full description recorded as a part of the permanent record.

Final Measurements.—In trench work the length of each size of pipe should be recorded as laid in each section of the work, and an accurate record made of the size, location and description of all branches and specials built in the work. Unless the engineer is constantly upon the work it may not always be practicable to secure ties to all branches before they are covered. Where this is impracticable, the inspector should provide a suitable marker which can be measured when the engineer is next available. This is sometimes done by placing at the branch a long pole which extends to the surface of the street. Other engineers require a proper mark upon the sheeting or a stake driven at one side and "tied" into the branch. Many mistakes have occurred in the location of branches due to these indirect methods of measurement and it is preferable to require that the branches be left uncovered until measurements are taken. All structures such as manholes, catch basins and flushing chambers should be measured and carefully recorded immediately upon their completion. The length, size, location and method of construction of underdrains should be accurately measured and recorded. All sheeting "left in place" should be recorded, showing the location of the same together with its length and dimensions.

For sewage works and other structures the grade of all finished excavations should be taken by means of cross-sections on the same stationing as were the original cross-sections, and the limits of ledge excavation should be clearly shown by the records.

Estimates.—Although the contract may only require the making of monthly and final estimates, it is frequently desirable that the engineer make approximate daily estimates of certain portions of the work. For example, where a concrete structure is being built, it may be desirable to make daily estimates of the quantity of concrete placed, and compare them with the record of the quantity of cement and aggregate used. The quantity of concrete produced by the use of a given quantity of cement and the required proportions of aggregate may be determined approximately by the use of Wm B. Fuller's formula. A comparison of the quantity of concrete actually placed with that computed in this way may disclose errors in mixing, or in the size and placing of forms. Fuller's rule is simple and may be expressed as follows:

> "Divide 11 by the sum of the parts of all the ingredients, and the quotient will be the number of barrels of Portland cement required for 1 cu. yd. of concrete. The number of barrels of cement thus found, multiplied respectively by the "parts" of sand and stone, will give the number of barrels of each required for 1 cu. yd. of concrete, and multiplying these values by 3.8 (the number of cubic feet in a barrel), and dividing by 27 (the number of cubic feet in a cubic yard), will give the quantities of sand and stone, in fractions of a cubic yard, needed for 1 cu. yd. of concrete. To express this rule in the shape of formulas: Let c = number of parts cement; s = number of parts sand; g = number of parts gravel or broken stone; then $P = 11 + (c + s + g)$ = number of barrels Portland cement required for 1 cu. yd. of concrete. $3.8Pg/27$ = number of cubic yards of stone or gravel required for 1 cu. yd. of concrete." (Taylor & Thompson's "Concrete," second edition, page 16.)

Measurements should be taken monthly covering the total amount of work done to date under each of the items of work as enumerated in the contract. These measurements should be approximately complete and serve as the basis of the monthly estimates upon which the contractor draws his intermediate payments.

At the completion of each portion of the work and at the completion of the entire undertaking, final measurements should be taken with necessary accuracy, to determine the actual amount of work performed upon which final payments are to be made to the contractor. The computations for these final statements should be carefully made, systematically arranged on computation sheets, thoroughly and intelligently checked, and carefully preserved as a part of the construction records.

RECORDS

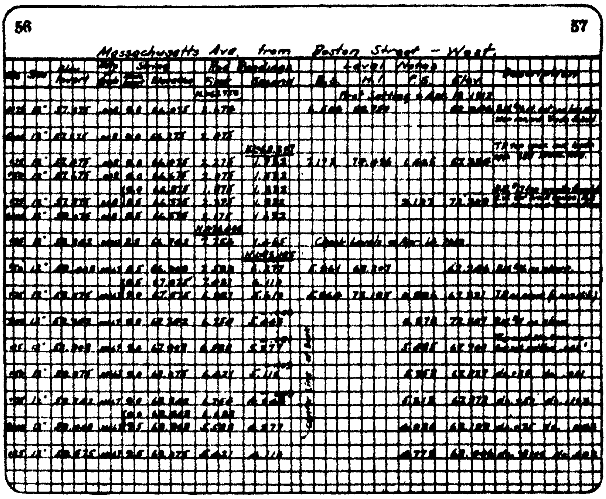
All records made in staking out sewer trenches and structures should be preserved in standard note-books. Such records should be systematically arranged, so that all steps are shown and are easily intelligible. They should be thoroughly indexed during the progress of the work.

For sewer work these notes should show not only the elevation of the invert for each station where grades are given but also the rate of grade, or slope of sewer, the size of sewer, the elevations given upon the batter boards or grade pegs, and all level notes by means of which such elevations are given. All secondary readings given in "checking up" of grades should also be recorded. A form of notes suggested for the staking out of sewers is shown in Fig. 10.

It takes but a little time to record the character of the soil encountered in trench excavation, and it is highly desirable that such records be made. The information may be of service not alone to the department for which the work is undertaken, but also to other departments, public service corporations and private parties having occasion later to excavate in the same locality. Such records should show the characteristics of the various soils, ledge, etc., together with a memorandum as to the elevation of ground water, note being made of the season of the year, the weather and temperature to afford as much information as possible as to the conditions existing at the time the data were recorded.

Accurate location of all pipes, culverts, conduits and other buried structures encountered in the excavation should be made and recorded permanently. Each sheet should be dated and the initials of the note-taker preserved.

All official computations should be made on standard computation sheets, each sheet being headed with a description of the computation involved, together with the date and initials of the computer, each in a space allotted for it near the head of the sheet. To prevent loss of such sheets during computation, it is desirable to keep them at all times in a ring-book, and when any set of computations is completed they should be fastened together on the left-hand edge, so that they may still be used in the ring-book if desirable, clearly marked on a title page, and if not required for frequent reference, filed away. All such computation sheets should show the source of all information by means of reference to the note-books, diagrams or other data used in the computation. The summarized findings should always be clearly indicated to save time in assembling and checking data. The use of red ink for recording the results will save time and lessen the chance for oversight.



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57

Massachusetts Ave. from Boston Street - West.

FIG. 10.—Form of notes for staking out sewer grades; kept on facing pages of note-book.

Each of the two pages of this note-book is 4½ in wide and 7 in high. The ruling on the left-hand pages is blue with every fourth vertical line red, while that on the right-hand pages is blue except for a vertical red line down the center. The lines are $\frac{1}{4}$ in. apart vertically and horizontally. The date of the work and the initials of the instrumentman, rodman and note-taker should be placed on the top of one of the pages.

Each field note-book should be thoroughly indexed within its own covers on pages allotted for the purpose at the beginning of the book. This index should also be recorded in a general office index, either in a book provided for the purpose or in a card index.

As the completed structures rarely conform exactly with contract or preliminary drawings, it is important and customary to provide, at the completion of the work, record drawings showing in detail the structures as finally completed.

Record drawings may be provided by making alterations upon the tracings of the contract drawings, although usually it is better to make new drawings for this purpose. One reason why this latter course is preferable is that it makes it possible to preserve unaltered the original preliminary or contract drawings. Either the originals, or copies of contract drawings, should always be preserved for future reference, at least until final settlement has been made with the contractor and all claims for damages arising out of the contract have been fully satisfied, and where practicable, it is desirable to keep them indefinitely, as questions are likely to arise in the consideration of which the contract drawings may be of considerable value.

Record drawings should show the exact location and dimensions of all specials, branches, house connections, manholes, flush-tanks, catch-basins, inlets and the details of all other structures built. They should show the elevation of inverts and the slopes of sewers, and should have upon them references to note-books containing the data upon which the drawings are based.

Record profiles are often made and are frequently helpful in future studies. They may be placed upon the sheets upon which the other record drawings are made, or they may be drawn upon separate sheets, as proves more desirable. They should show the kind, size, slope and elevation of the sewer, and where practicable, it may be well to indicate the kinds and stratification of the materials excavated. They should show the location and names of cross-streets and alleys, and location of pipes, conduits and other structures encountered.

In most cases a scale of 1 in. to 40 ft. will be found practicable and most convenient for record drawings and for record profiles 1 in. to 40 ft. for the horizontal scale and 1 in. to 4 ft. for the vertical scale. Elevations and sections of details are preferably made on a scale of 1/4 in. to 1 ft. or 1/2 in. to 1 ft., depending upon the size and character of the detail.

Tracing cloth of the best quality has proved satisfactory for record drawings. Where the drawings are subject to frequent use, prints should be provided, bound in loose leaf covers, and the original drawings, laid flat, should be filed in a dry, fire-proof vault. The originals should be used only for the reproduction of prints and for making additions or corrections from time to time, as may be required. The older practice of using egg shell paper mounted on muslin for record drawings has the distinct advantage that changes can be made without serious injury to the paper. This material, however, is subject to the great disadvantage that reproduction from it can only be made by tracing or photography.

Record profiles are preferably made on tracing cloth, although the comments already made with reference to other record drawings apply to the record profiles. As all papers and cloths are subject to shrinkage, it is desirable upon important work to provide vertical and horizontal graphical scales, from which the amount of shrinkage in either direction may be determined. This, however, is rarely done and will probably prove of little use if all dimensions are shown, which is very desirable.

Photographs should be taken before, during and upon the completion of all work. It is highly desirable that these photographs should be taken at comparatively regular intervals in order to give thereby a clear conception of the rate of progress of the construction work. If it is possible to select a few points where periodical photographs may be taken with the camera pointed in exactly the same direction each time, the uniformity of the view will be of great help in comprehending the progress which has been made in the interval between consecutive photographs. Sometimes it may prove desirable to erect a semi-permanent scaffold or stage at two or three well-chosen points, so as to elevate the camera and thus prevent to some extent the foreshortening which may take place when the camera is used from the surface of the ground.

Photographs are useful in many ways. They serve to convey to the owner, chief engineer and others who are interested in the work but are unable to watch its progress, a clear conception of the progress of the work. They serve as a record which often carries more weight in legal proceedings than does a written report. The fact that systematic and well-chosen photographs are preserved may deter parties from pursuing doubtful claims through the courts. Photographs showing the details of construction are a valuable record of methods of construction.

Each photograph should be assigned a number conforming to some definite system of numbering and each plate and film should be permanently marked with its assigned number, its date and a brief description to identify it. It is desirable that this notation should be on the gelatin side of the films and plates and the lettering should be executed backward or in reverse type (photoscript) so that in printing, it may be easily read.

COST KEEPING

Well kept records of the cost furnish the engineer and sewer builder with information which may be useful in forming estimates for future work of similar nature conducted under similar conditions. Such records, provided they are promptly and accurately worked up, enable the engineer to ascertain during the progress of the work the degree of efficiency developed by the organization. With this information it is frequently possible for the engineer to call the attention of the contractor to conditions which are the cause of inefficient results, thus enabling the contractor to place the work upon a more profitable basis. Where the work is being done by direct labor an effective system of cost accounting may result in a large saving in expense.

FORM A.—USED FOR RECORDING LABOR*

New Salem, Mass., Sewerage System, Section (1), Smith, Jones & Brown, Contractors, 1911. Labor Laying 12-in Pipe

Class of labor	Hourly rate	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Sum	Amount
March								Sun				Rain P M			Sun							Sun							Sun					
Supt	$.50	1	1	1	1	1	1		1	1	1																						25	$ 12 50
Foreman	35	3	3	3	3	3	3		3	3	3	2																					70	24 50
Pipe layer	30	9	9	9	9	9	9		9	9	9	5																					230	69 00
Pipe layer, ass't	25	9	9	9	9	9	9		9	9	9	5																					225	56.25
Tender	.25	9	9	9	9	9	9		9	9	9	5																					232	58 00
Mortarman	20	9	9	9	9	9	9		9	9	9	5																					230	46.00
Labor	.17½	18	9	18	18	18	9		27	9	18	5																					340	59.50
Labor pumping	17½	24	24	24	24	24	24	24	33	33	33	33																					820	143.50
Total	March	82	73	82	82	82	73	24	100	82	91	60																					2172	$469.25

* Time recorded in hours. The records for subsequent months are kept below this on the same sheet

Necessary Data.—Information should be recorded under main divisions of engineering and supervision, labor, materials, machinery and tools, and overhead charges of contractor or direct labor organization.

All labor employed should be classified according to the rates of pay and the work performed by the several classes of labor, such classifications being made under each item of work for which separate payments are provided in the contract. If the work is divided into sections, then similar records should be kept separately for each section of the work.

Similarly for each item of the contract in each section of the work a record should be kept of the kind and grade of material, rated according to the price paid for each.

Similar classifications and distributions should be kept under this heading for each type of machine and for machines of various rental rates.

There are many items the cost of which cannot be directly charged to any one part of the work. Such charges may be anticipated, in part, at the outset, and the cost distributed pro rata to the several subdivisions of the entire work from month to month as the work progresses, in order that each item may bear its proportional part of the entire expense and thus be on a comparable basis at all times. At the close of the work, and

FORM B.—USED FOR RECORDING MATERIALS AND SUPPLIES

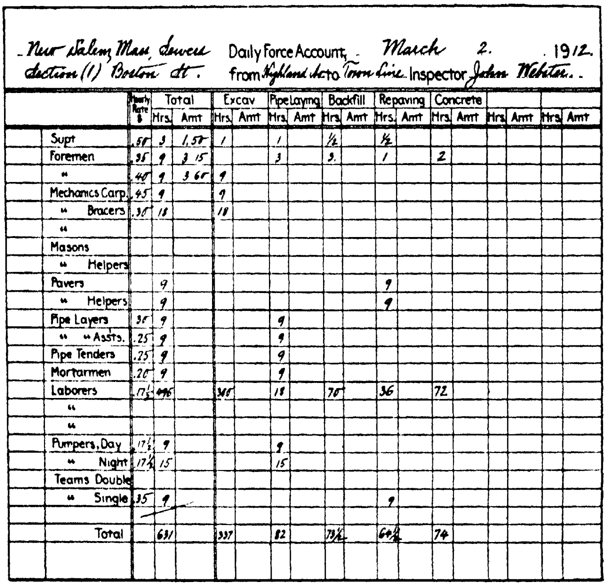
New Salem, Mass., Sewerage System, Section (1), Smith, Jones & Brown, Contractors, 1911. Laying 12-in. Pipe

Date rec'd.*	Material	Quantity	Cost delivered		Use	Mar	April	May	June	July	Aug.	Sept.	Oct.	Value remaining
			Price	Amount										
	Lumber													
3/3	2 in. × 8 in plank.	5M ft	18.00	90 00	Excavation	30% 27 00	25% 22 50	20% 18 00	15% 13 50	10% 9 00				0.00
3/25	2 in × 8 in. plank	10M ft.	18 00	180 00	Excavation	3% 5 40	30% 54 00	25% 45 00	20% 36 00	15% 27 00	7% 12 60			
4/10	2 in. × 8 in. plank	6M ft	18.00	108 00	Excavation		20% 21 60	25% 27 00	25% 27 00	20% 21.60	10% 10 80			
5/1	2 in × 8 in. plank	5M ft	18 00	90.00	Excavation			30% 27 00	25% 22.50	20% 18.00	15% 13 50	10% 9 00		
7/15	2 in. × 8 in. plank.	10M ft.	18 00	180 00	Excavation					20% 36 00	30% 54.00	25% 45.00	10% 18 00	27 00
	Note: Separate sheet should be allowed for items purchased in numerous installments.													
	Timber													
3/3	4 in. × 6 in..... ...	2M ft.	18.00	36 00	Excavation	30% 10 80	25% 9 00	20% 7 20	15% 5 40	10% 3 60				
3/25	4 in. × 6 in.. ..	3M ft.	18 00	54.00	Excavation	3% 1 63	30% 16 20	25% 13 50	20% 10 80	15% 8.10	7% 3 78			
	Cement (Atlas)													
2/2	100 bbl. storehouse........		1 60	160 00	See separate sheet	10% 16 00	40% 64.00	30% 48.00	20% 32 00					
5/20	100 bbl. storehouse.. ...		1 55	155 00	do				5% 7.75	40% 62 00	55% 85 25			
7/5	150 bbl. storehouse..........		1 62	243 00	do.						3 33% 8 10	40% 97.20	6.67% 16.20	121.50
	Crushed Stone													
4/10	25 tons		0.90	22 50	Concrete foundation		15.00	7.50						
5/15	50 tons..................		0.90	45.00	Foundation underdrains culverts			11% 5.00	61% 27.50	28% 12.50				

* In the dates given below the number in front of the fractional mark indicates the month and the number following, the day, as 3/3 = Mar. 3.

in large undertakings at intermediate times, such figures should be computed with accuracy and the preliminary figures revised accordingly.

The overhead charges and the incidental expense to be thus distributed will include the following items: Field office rentals; salaries of superintendents, timekeepers, bookkeepers and clerks; cost of office labor and supplies; maintenance and depreciation of vehicles; rental; value of horses and carriages; cost of transportation of labor; telephone charges, insurance, liability insurance, and miscellaneous expenses.



New Salem, Mass, Sewers Daily Force Account, March 2. 1912.
Section (1) Boston St. from Highland Av. to Town Line. Inspector John Webster.

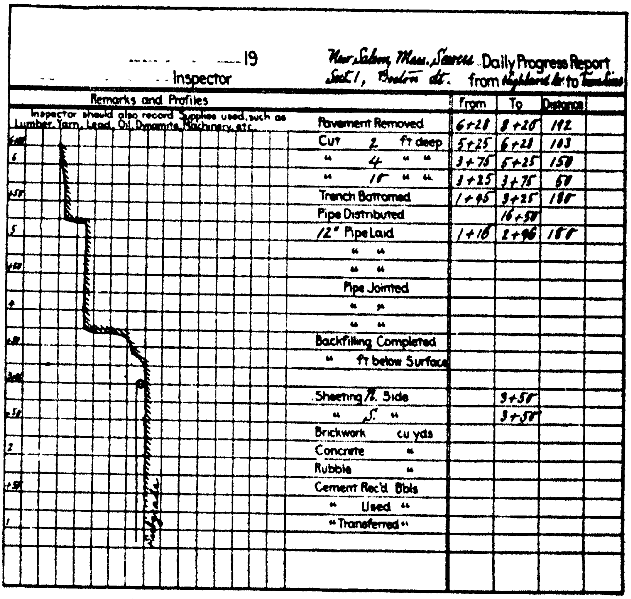
		Hourly Rate $	Total		Excav		Pipe Laying		Backfill		Repaving		Concrete					
			Hrs.	Amt	Hrs.	Amt	Hrs.	Amt	Hrs.	Amt	Hrs.	Amt	Hrs.	Amt	Hrs.	Amt	Hrs.	Amt
	Supt	.50	3	1.50	1		1		½		½							
	Foremen	.35	9	3 15			3		3.		1		2					
	"	.40	9	3 60	9													
	Mechanics Carp.	.45	9		9													
	" Bracers	.30	18		18													
	"																	
	Masons																	
	" Helpers																	
	Pavers		9								9							
	" Helpers		9								9							
	Pipe Layers	30	9				9											
	" " Assts.	.25	9				9											
	Pipe Tenders	.25	9				9											
	Mortarmen	.20	9				9											
	Laborers	.17½	496		300		18		70		36		72					
	"																	
	"																	
	Pumpers, Day	.17½	9				9											
	" Night	.17½	15				15											
	Teams Double																	
	" Single	.35	9								9							
	Total		631		337		82		73½		64½		74					

FIG. 11.—Daily force account blank (face).

To obtain such records, systematic methods must be adopted, and these methods will vary according to the character of the work involved. The engineer in charge of such records should have a clear understanding of construction methods and also a grasp of commercial methods, and he should have an analytic mind and be able to interpret the statistics and records thus obtained. He should have such assistance as will enable him to collect the information as well as to record and summarize the same.

It is frequently possible to have the field inspector record the labor, materials, and machinery employed in the work, under the direction of the cost-keeping engineer, to whom the notes should be sent daily, although it may prove more desirable to have an entirely independent organization for the purpose. Above all, the material should be promptly worked up so that the cost data may be compared with the monthly estimates.

Printed Forms.—It is desirable to have forms printed so as to reduce the labor of entering and classifying the many items in the field, and to insure the proper subdivision of the items, especially if such information is to be collected by the field inspectors. In the latter case, cards should be provided so that the information may be sent to headquarters by mail or collected by a clerk of the department daily.



——————19

——————Inspector

New Salem, Mass. Sewers Daily Progress Report

Sect. 1, Boston St. from Highland Av. to [illegible]

Remarks and Profiles

Inspector should also record Supplies used, such as Lumber, Yarn, Lead, Oil, Dynamite, Machinery, etc.

	From	To	Distance
Pavement Removed	6+28	8+20	192
Cut 2 ft deep	5+25	6+28	103
" 4 " "	3+75	5+25	150
" 15 " "	3+25	3+75	50
Trench Bottomed	1+45	3+25	180
Pipe Distributed		16+50	
12" Pipe Laid	1+16	2+96	180
" "			
" "			
Pipe Jointed			
" "			
" "			
Backfilling Completed			
" ft below Surface			
Sheeting N. Side		3+50	
" S. "		3+50	
Brickwork cu yds			
Concrete "			
Rubble "			
Cement Rec'd Bbls			
" Used "			
" Transferred "			

FIG. 12.—Daily force account blank (reverse).

The blank shown in Figs. 11 and 12 has been found very convenient for records made by the field inspectors. These forms measure about 8 × 7 in., may be folded and carried inside of the regular field note-books and may be held in place by a rubber band or a string. The total force is recorded in the first set of double columns, whereas the subdivisions of the forces are made in the columns following, appropriate headings being

Form C.—Tools, Equipment and Repairs

New Salem, Mass., Sewerage System, Section (1), Smith, Jones & Brown, Contractors, 1911. Laying 12-in. Pipe

Date	Article	Cost delivered		Use	Monthly rental, per cent.	Mar	Apr.	May	June	July	Aug.	Sept	Oct.	Amount charged off	Value remaining
		Price	Amount												
	$ *Tools*	$	$												
2/25	Shovels, rd. pt., 4 doz ...			Excavation	10	$	$	$	$	$	$	$	$	$	$
	Shovels, sq. pt., 1 doz. ..			Excavation	10										
	Picks, 4 doz...			Excavation	10										
	Grubs, 1 doz....... ..			Excavation	10										
	Handles, 10 doz.. . .			Excavation	10										
	Hammers, 16 lb., 2.			Excavation	10										
	Hammers, 8 lb., 4. ...			Excavation	10										
	Axes, 2........... .			Excavation	10										
	Saws, cross cut, 2. ...			Excavation	10										
	do., 2..			Excavation	10										
	Mauls, wooden, 4.. .			Excavation	10										
	Total			Excavation	10										
		Note: Separate sheets may be used for equipment and for repairs.													
	Equipment														
2/25	Edson pumps, 2			Excav pipe lay	5										
	Wheelbarrows, 12....			Excav. conc.	8										
3/15	Concrete mixer...	900.00	900.00	Concrete	5	22 50	45.00	45 00	45.00	45 00	45 00	45 00	45 00	337 50	562.50

Form E1.—Total Cost of Pipe Laying

Month	Pipe laid, lin ft.	Labor		Materials and supplies		Tools, equip. and repairs		Overhead charges		Total cost		Notes, remarks, etc.
		Total	Per ft.	Total	Per ft.	Total	Per ft.	Total	Per ft.	Sum	Unit	
March. . .	4840	$469.25	$0.097	$	$	$	$	$	$	$	$	Sewer pipe, specials, etc., furnished to contractor, on cars. av. haul = ¾ mi.
April												
May.... ..												
June.......												
Etc.												
Total												
Unit cost..												

Note.—This is used with Form E2 reproduced on page filled in for each. On the right-hand portion of the reverse side provision is made for the record of the daily progress, while on the left hand portion is space for sketches or profiles and records of supplies received, etc.

FORM D.—GENERAL AND OVERHEAD CHARGES

New Salem, Mass., Sewerage System, Section (1), Smith, Jones & Brown, Contractors, 1911. Laying 12-in Pipe.

Classification	Monthly rate	Proportion for this job	Total charges to this job					
			Mar.	Apr	May	June	July	Aug.
Rent	$		$	$	$	$	$	$
Main office	60 00	10%	6.00	6 00				
Field	20 00	100	20.00	20.00				
Telephone								
Main office service	10 00	10%	1 00	1 00				
Main office tolls			2 00	1 50				
Field office service	3 00	100	3.00	3 00				
Field office tolls		100	1.50	1 50				
Telegrams		100	0 75	1 25				
Clerical force								
Main office	300 00	10%	30.00					
Field office								
Timekeepers	75 00		75.00	75 00				
Bookkeeper...	90.00	100	90.00	90 00				
Cost keeper	80.00	100	80.00	80 00				
Stenographer	50 00	100	50.00	50 00				
Livery and auto service								
Automobiles rented	125 00	100	125.00	125 00				
Automobile repairs		100	50 00	40 00				
Automobile chauffeur	60 00	100	60 00	60.00				
Carriage hire	40 00	100	40 00					
Wagon hire	40 00	100						
Insurance								
General plant								
Expense loading								
Expense unloading								
Freight								
Transportation								
Firm								
Labor								
Miscellaneous								
Total								

	Proportion
Earth excavation	%
Pipe laying	%
Backfill	%
Re-paving	%

These force account records should be submitted to the cost-keeping engineer daily, and the information contained therein should be at once entered on blanks prepared for the purpose. On Form A the daily amounts of labor are recorded on separate sheets for each classification into which the accounts are subdivided. Where only a few classes of labor are employed, thus requiring but a few lines for each month's record, records of several months may be placed on one sheet, thus economizing space. The quantities of materials and supplies are recorded on Form B. Where numerous installments of a given article are anticipated during the progress of the work, it is desirable to reserve a sheet for each classification, although several such groups may be placed on one sheet where only a few items of each are anticipated.

As the material supplied in one month may serve its purpose during the following months, it is desirable to distribute this cost over the entire period during which it will be used, and if it has value at the completion of the work this value should be noted, as shown in the last column. For instance, the 2 × 8-in. plank used for trench sheeting, purchased in March, may not be all used until the following month, and then in all probability it will be withdrawn and used again and again. Its cost has, for the purpose of illustration, been divided as follows: March, 30 per cent.; April, 25 per cent.; May, 20 per cent.; June, 15 per cent.; July, 10 per cent.; after which the lumber is assumed to have no value; whereas the cost of the lumber purchased July 15 is distributed through the months of July, August, September and October, and 15 per cent. is shown as salvage at the completion of the work.

FORM E2.—SUMMARY OF LABOR COSTS IN PIPE LAYING

New Salem, Mass., Sewerage System, Section (1), Smith, Jones & Brown, Contractors, 1911. Laying 12-in. Pipe

Month	Supt.	Foreman	Pipe layer	Asst pipe layer	Tender	Mortar-man	Labor	Labor pumping	Total $
Wage-rate per hour	$0.50	$0.35	$0.30	$0.25	$0.25	$0.20	$0.17½	$0.17½	
March	12.50	24.50	69.00	56.25	58.00	46.00	59.50	143.50	469.25
April									
May									
June									
July									
August									
Sept.									
Oct.									
Total									
Cost per foot	0.0025	0.005							

In a similar way the expenditures for tools, equipment and repairs are recorded on Form C. The general and overhead charges will be ascertained by the cost-keeping engineer and will be recorded on Form D and similarly distributed.

The results obtained and recorded on the forms just described are summarized on Form E. In addition to the summarized detail costs recorded herein, the unit costs should be worked out and recorded, with a separate blank for the several divisions of the work, such as earth excavation, pipe laying, refilling, re-paving, etc. We are thus able to compare the unit costs, month by month, for each of these divisions, each subdivided into labor, materials and supplies, tools, equipment and repairs, overhead charges, and total unit costs.

If it is desirable to have this detailed information weekly instead of monthly, as shown on these blanks, four or five additional lines may be allotted to each month instead of one line as shown, and the weekly figures may be inserted in small figures in pencil or in an ink of a different color from the monthly record, without great additional labor or confusion.

PROGRESS

At the close of each day the inspector should record the stations to which the several parts of his work have advanced during the day, such as

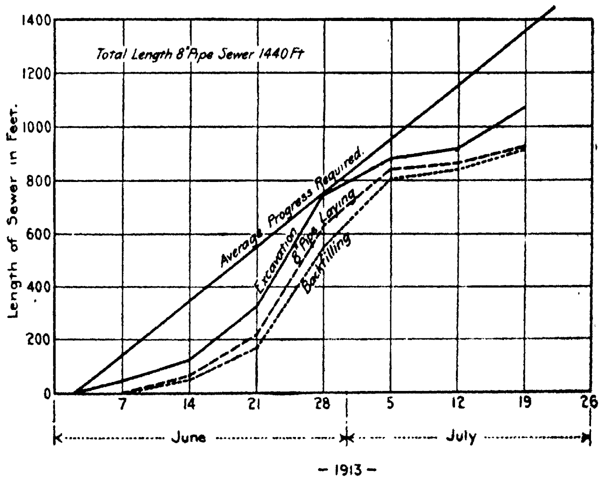


FIG. 13.—Progress Diagram.

trench bottom, pipe laid, excavation (in zones), pavement removed backfilling partially complete, backfilling complete, etc.

Unless the daily measurements are sufficiently accurate and if the weekly cost accounts are to be worked up accurately, additional measurements should be taken to show the progress made during the week. These records should be entered on the appropriate daily report blanks.

The monthly measurements taken primarily as a basis for the monthly estimates of payments due the contractor should be recorded in such a way as to show the progress made during the month and in such detail as will permit the determination of all the unit costs desired by the cost-keeping engineer.

Actual and Required Progress.—It is desirable to formulate at the beginning of the work a schematic outline of the progress required for its completion at the time specified. Such an outline may be shown in tabular form or by a diagram. Progress data procured at the intervals selected may be tabulated or plotted upon the diagram, using the calendar weeks or months as abscissas and the accumulated sum of the man-days of labor, cubic yards of excavation, feet of sewer pipe laid, or other pertinent unit, as ordinates. By comparing the actual progress made with that anticipated at the outset, it is possible to ascertain at any time how close to the original forecast the work is being executed. Such schedules may be helpful to the contractor as well as to the engineer, enabling him to gage his force and to provide plant so as to attain the required rate of progress. In addition to the chart showing the total or general progress of the undertaking separate charts may be required for different sections of the work and for different portions of the work upon each section, as for example, for excavation, for pipe laying, for placing concrete and for backfilling. A chart for recording progress is illustrated by Fig. 13.

COST OF ENGINEERING AND SUPERVISION

The cost of engineering and supervision depends upon the size of the project, the extent of preliminary investigations, surveying and mapping required, the thoroughness with which studies, designs and contract drawings are executed, the amount of care and watchfulness put onto the construction, the difficulties encountered in building the works, and many other conditions, all of which make it impossible to state any proportionate amount of the cost of the complete project which must be devoted to engineering. In a general way the cost will range from 7 1/2 to 15 per cent., although there are many cases in which it will exceed the upper limit and in some cities where there are regularly organized departments doing a nearly uniform amount of relatively simple work from year to year it may fall to 5 per cent. of the total cost of the projects.

These costs often include, or are closely related in the accounting system to, the expenditures for rights-of-way, damage suits and sundry other items. Upon contract work aggregating nearly four million dollars at Louisville the expenditures were as indicated in Table 4. The preliminary expenses cover such work as topographic survey and mapping, preliminary studies and preparation of general schemes for the project. The entire work was done in about seven years, 1906–1912, although little construction work was executed during the first two years and only a relatively small amount in 1912.

TABLE 4.—DISTRIBUTION OF EXPENSE INCLUDING PAYMENTS TO CONTRACTOR, ON CONTRACT WORK TO JANUARY 31, 1913, LOUISVILLE, KY.

Item	Total cost	Per cent. of total expenditures
Preliminary engineering and administration expenses	$57,271.74	1.51
Administration	78,025.03	2.05
Engineering	336,544.87	8.86
Rights of way	12,319.36	0.32
Castings and other metal work supplies	15,461.29	0.41
Damage suits (exclusive of rights of way)	8,307.52	0.22
Amount of payments to contractors	3,289,330.89	86.63
	$3,797,260.70	100.00

Note.—Work aggregating slightly over $400,000 was done by direct labor. This should be taken into account when considering Preliminary Engineering and Administration Expenses.

Where engineers are to enter into contract to provide engineering and upervision they should exercise great care to set forth fully and clearly ust what work is covered by the agreement. Some engineers stipulate hat such a contract shall not cover services in court arising out of tigation, and in any event this item should be specifically mentioned the work is to be done upon a percentage or lump sum basis. The robability of delay in completing the work covered by construction ontract should also be taken into consideration and it is entirely easonable for the engineer to be allowed additional compensation for ach day of delay in such completion or for the cost to him resulting om such delay as may occur.

CHAPTER III

EXCAVATION

The excavation is usually the part of sewer construction most important to the contractor, as upon it the most money is generally made or lost. The cost of work done under this item and for which there is usually but one payment covers a multitude of things, among which may be mentioned the excavation proper, handling water, sheeting and bracing, backfilling, re-paving, hauling waste material to the dump, rental of machinery, coal, oil, waste, minor repairs, and the larger portion of the overhead charges, such as office rent, capital charges, and compensation for time spent by the contractor and his superintendent. To excavation must also be charged a part of the cost of employees not actually engaged in excavating, such as engineers, firemen, tagmen, watchmen, timekeepers, bookkeepers, and a number of others.

To handle excavation to advantage requires good management and excellent judgment on the part of the contractor, engineer or foreman. Such judgment is the fruit of long experience in which he has had to do with materials of many kinds and under many conditions. He must be able to judge from his past experience how to handle the work, whether the excavation should be done by hand, or if by machinery, what type of machines and how many he will put on the work. It is not uncommon to find work much over-planted, which always results in excessive cost, and often in actual loss upon the whole contract.

The materials entering into the sewer usually cost about the same as the labor required for its construction, but there is generally little profit to the contractor in the materials furnished. The chief profit comes through the economical handling of the work so that the labor cost may be reduced to a minimum. The element of time is also an important item which is often overlooked. It has an important bearing upon excavation. The longer the work lasts the greater are likely to be the overhead charges, and also the charges for machinery and the cost of engineers, firemen, tagmen, etc., and even larger items chargeable against unnecessary delay, such as the extra expense involved in carrying on the work under unfavorable weather conditions. Rapid work during the summer time, when costs can be kept low, may avoid a large unnecessary cost which will result if the work is prolonged into the winter. A high charge against the contractor on account of liquidated damages for delay often inures to his benefit much more than to the benefit of the party with whom he contracts to do the work.

MATERIAL TO BE EXCAVATED

A great variety of materials are encountered in sewer excavation, such as sand, gravel, loam, clay, hardpan, quicksand, disintegrated rock, boulders and ledge. These materials merge into each other so that frequently there is no sharp line of demarcation between them. Some of them also vary greatly from season to season. The surface materials in the northern and colder climate are relatively soft and easy to excavate during the warm season of the year, but in the winter become frozen and in some cases are nearly as expensive to excavate as solid rock. Many trenches have been excavated with comparative ease in dry weather, which would have been excavated with the greatest difficulty had the ground water been high and had frequent rains occurred during the progress of the work. These facts have often misled contractors who have based their estimates upon their observation of the way in which similar work was being done, or their judgment as to how it should be done, under favorable weather conditions. When overtaken by unfavorable conditions, such as rain and frost, easy and inexpensive work has become difficult and costly. While many different kinds of materials have to be excavated, there are two general classifications in common use in the drawing of contracts for sewers, namely, earth excavation and rock excavation.

Classification.—Under earth excavation is included all excavation of earthy substances, except ledge rock or large boulders.

The line of demarcation between earth and rock excavation is one which has caused much dispute and litigation. There is often no sharp dividing line between them, and the opinions and judgments of different engineers and contractors are often at variance upon this distinction. In the East there is generally not so much question as to the definition of rock as in the Middle and Western portions of the country, for in the East the rock is generally hard and not seriously disintegrated, in which condition it is easily distinguished from earth. Even in the East, however, there are cases where the rock overlying hard ledge rock which requires, without question, drilling and blasting for its excavation, is disintegrated to such an extent that it can be removed by the use of pick and shovel and without drilling and blasting. Such material is generally classified as earth.

Definitions of Rock Excavation.—In view of the difficulties and disputes which have arisen over the definition of rock the following quotations from contracts drawn by engineers of experience are given:

"Where rock is encountered of such hardness that it can be most economically removed by blasting, the contractor shall remove the same from the trench, and shall receive pay therefor . . . at the price per cubic yard for the rock excavation mentioned in the contractor's proposal." (Alvord and Burdick, consulting engineers, Chicago.)

"Only such ledge or rock in trench as cannot be readily removed with a pick and shovel and requires blasting for its removal, and which has been measured by the engineer before blasting, and all boulders of 1/2 cu. yd. or more in volume which are removed from the trench, will be estimated as rock excavation. The bottom of the trench shall be excavated to a depth of 6 in. below the outside of the pipe, and shall be refilled in a proper manner with suitable material." (Hering & Fuller, consulting engineers, New York.)

"Only ledge rock as, in the opinion of the engineer, requires blasting for its removal, and boulders of 1/2 cu. yd. or more in volume, shall be measured and paid for as rock excavation." (Hering & Gregory, consulting engineers, New York.)

"Rock excavation shall include hard rock of such nature that, in the opinion of the engineer, it cannot be removed by picking or barring, found in ledge or detached boulders containing more than 1/2 cu. yd. each. All other materials found in excavation, however hard, stiff and compact, including soft and disintegrated rock which can be removed without the aid of explosives, shall be classed and paid for as earth." (Frank A. Barbour, consulting engineer, Boston.)

"Only such ledge or rock in trench as cannot be readily removed with a pick and shovel and requires blasting for its removal, and which has been measured by the engineer before blasting, and all boulders of 1/2 cu. yd. or more in volume which are removed from the trench, will be estimated as rock excavation." (George W. Fuller, consulting engineer, New York.)

Allen Hazen writes to the authors: "My feeling would be that I should write it (rock specification) for any particular conditions for which I was designing the work, based upon local conditions."

W. A. Cattell, consulting engineer, San Francisco, stated to the authors:

"I have never yet found it necessary to use any classification for excavation for any kind of engineering work. It has been my observation that the definitions and classifications generally in use in engineering specifications of this nature have been such fruitful sources of dispute and litigation, that it is best to eliminate them altogether whenever it is possible to do so. There are, of course, some conditions under which it might be necessary or advisable to specify certain classifications to be used in measuring and paying for excavated material, but in a great majority of cases they can and should be omitted entirely. This may seem somewhat arbitrary to those who have always followed the old method of classification, but I have found it to work out very well in actual practice."

M. M. O'Shaughnessy, city engineer of San Francisco, states that it is not the practice of his office to distinguish between rock and earth excavation in letting contracts for sewer or other work involving excavation.

Another method of specifying rock excavation by classifying under loose rock and solid rock and paying two prices for these materials, is illustrated by the following quotation from Burns & McDonnell's form of contract for the excavation of trenches at Riverside, Cal.:

> "Loose rock shall include all masses of stone and detached rock containing no single rocks or boulders larger than 9 cu. ft. in volume and containing not more than 40 per cent. of earthy material; also all decomposed granite or other rock which can be practicably quarried without blasting, even though blasting may be done to more conveniently accomplish the excavation of this material. The classification of materials shall in all cases be determined by the engineer.
>
> "Solid rock is defined as any material which cannot be practicably excavated without drilling and blasting. All boulders, ledge rock or stratified rock of such material having 9 cu. ft. or more of volume shall be paid for as "solid rock." The engineer shall in all cases decide whether or not it is practicable to excavate the material without drilling and blasting, and the fact that the contractor may find it expedient to blast any material which in the opinion of the engineer may be practicably excavated without blasting, shall in no way change or modify this classification, nor entitle the contractor to solid rock price for material so removed."

The definition of rock in sewer specifications adopted by the Board of Local Improvements of Chicago, in 1911, is as follows:

> "Wherever the word 'rock' occurs in these specifications it shall be interpreted to mean any material geologically in place and of a hardness when first exposed of three or greater in the scale of mineral hardness, which corresponds to the hardness of the transparent variety of calcite. Other materials shall not be classed as rock, although it may be more economical to remove the same by blasting. . . . No claim for an amount of money beyond the contract price of the work will be entertained or allowed on account of the character of the ground in which the trench or other excavations are made, except for the rock cutting heretofore specified."

It is evident that there is more or less difference of opinion among engineers in this country as to whether or not it is best to classify materials to be excavated under two headings, earth and rock. The prevailing opinion among eastern engineers, where rock is usually hard and fairly sharply distinguishable, is that such a classification should be made, while among the engineers of the Pacific Slope it appears to be customary to avoid this classification, grouping excavation of all kinds of materials under one item.

In much sewer work it is not easy for the contractor to ascertain even approximately the probable quantity of rock which he will be required to excavate. Provision has therefore generally been made in the contract that a definite unit price should be paid for rock excavation and it has been the understanding that the contractor would bid a price sufficient to cover the cost of excavating the rock, so that he might not lose, even though the quantity should be in excess of that expected; and on the other hand, the party awarding the contract should not pay an unnecessary amount, because of the fear of the contractor that rock might be encountered when in fact it was not.

Following are two quotations from the specifications for rock work which the authors have used with satisfactory results upon a number of contracts. The second is now used exclusively:

> "All excavations shall be classed and measured either as earth or rock, the latter to include all boulders 1/2 cu. yd or more in volume. All other materials found in excavation, however hard, stiff or compact, including soft or disintegrated rock which can be loosened with a pick, shall be classed and paid for as earth."
>
> "Rock, wherever used as the name of an excavated material, shall mean boulders exceeding 1/2 cu. yd in volume or solid ledge rock which, in the opinion of the engineer, requires for its removal drilling and blasting or wedging, or sledging or barring. No soft or disintegrated rock which can be removed with a pick; no loose, shaken or previously blasted rock or broken stone in rock fillings or elsewhere, nor rocks exterior to the maximum limits of measurement allowed, which may have been previously loosened in excavating for water pipes or other purposes and which, by reason of such loosening, may fall into the trench, will be measured or allowed."

HAND EXCAVATION

The sewer builder will find it advantageous to determine, if possible, prior to making estimates or bids the nature of the materials to be excavated; this can be done by means of test pits or borings, thus *limiting so far as practicable the uncertainty of his knowledge of the nature of the work to be performed. Where the construction must be carried on in a locality in which the contractor has previously done similar work, he will have a knowledge of local conditions which will aid him in making his proposals and in preparing for the work.* If local conditions indicate that sheeting will be necessary, the lumber and other materials and tools required should be provided and brought on to the ground for immediate use when the need develops, in order to prevent the caving of the banks, with consequent injury to adjacent pavements and the possible settlement of buildings or other structures. If water is likely to be encountered suitable pumping machinery should be provided at the outset, that the work may not be delayed while waiting to procure and erect such machinery.

In laying out a sewer trench to be excavated, it is desirable to line out the trench to the proper width by the methods described in Chapter II, and allot a given length of trench to each laborer or pair of laborers upon small work, or to a squad of laborers upon larger work, so as to furnish each man or group of men with approximately the same amount of work, as for example, one-half day's work, or in very deep trenches, a full day's work. In this way, the burden may be distributed equally among all of the men and the foreman may have an opportunity to distinguish between the efficient and inefficient workmen, while the men themselves are made to feel the spur of competition and comparison with others.

Loosening Surface.—Where the surface of the ground is hard and compact, either in its natural state or as paved with gravel or macadam, it must first be loosened, either by hand with pick and shovel or by means of a substantial plow drawn by horses or a traction engine. In narrow trenches such plowing is liable to weaken the top crust outside of the trench line and thus to increase the liability of caving banks, in which case the use of the pick and shovel may be preferred. Durable pavements, such as brick, asphalt, and wooden or granite block, must first be removed by bar and pick, and the concrete foundation taken out in like manner.

Opening Trench in Frozen Ground.—In the northern part of the country the frost penetrates from 1 to 3 ft. in depth in fields and wooded territory and from 3 ft. to 6 ft. in streets. It is found to enter the ground to the greatest depth in the center of the street, where the earth is compacted by traffic and is therefore a better conductor. In streets the frozen crust usually thaws both from the top and the bottom, so that just before the frost leaves the ground it is found in a thin layer about 6 in. thick perhaps 2 ft down from the top.

Opening a trench in frozen ground, by picking, is an exceedingly expensive and slow operation. In rare cases the frozen earth may be drilled and blasted but this method is seldom feasible in city streets because of the danger to persons and buildings. A common method of opening such trenches is by building fires on the surface of the street, usually at night, and thus thawing the ground so that it may be easily shovelled the following morning. Another convenient method of thawing the frost, if a steam boiler is available, is by steaming. This is done by building a number of wooden boxes open on the bottom. These boxes are of convenient length, usually 12 to 15 ft., about 10 in. high and approximately of the width of the trench. The boxes are laid with the open side down and holes are bored in the other side every 12 in. along the box and about every 2 ft. crosswise of the box. Each hole is provided with a wooden plug to prevent the escape of steam. When the boxes have been placed in position, they are banked up with soft earth to prevent the escape of steam and warm air from beneath them. One man is usually left out at night to tend the fire under the boiler and to steam out the frozen ground. This he does with a 3/4-in. gas pipe about 6 ft. long, provided with an iron cross-bar for a handle. To the end of *this pipe is attached a steam hose, the other end being open.* The operator places this pipe in a vertical position on the ground, passing it through one of the holes in the box. As the steam thaws the ground, he gradually works the iron pipe down until he has penetrated the whole layer of frozen ground. He then withdraws the pipe, plugs the hole and follows the same course in the next hole and so on until he has thawed the entire length of trench required for the next day's work. One man will usually be able to thaw out a sufficient area of street for a trench 4 to 6 ft. wide, 48 ft. long, in one night, where the frost is 4 ft. deep.

Pavements to be Preserved.—All paving material should be preserved and piled at one side of the street for use in replacing the pavement. Paving blocks, bricks, etc., should be placed in neat piles outside of the probable limits of the material to be excavated. The crushed stone from macadam pavements is frequently piled in a windrow on the opposite side of the trench from that used for storage of the balance of the excavation. Where trenches are deep or are likely to remain open for some considerable length of time, it is usually found that before this material is required for replacement in the trench much of it has been scattered and lost. If it is of good quality, it may be worth while to haul it away and store it in a vacant lot, or in a windrow on one side of each of several cross streets, care being taken not to obstruct driveways and to warn the public at night by the liberal use of red lanterns.

Excavated Material.—It is desirable to throw all material, except rock, excavated from the trench on one side of the trench. The material from the first 6 ft. in depth of the trench should be cast as far back from the opening as is possible at one throw, thus leaving space between this material and the trench for the material excavated from lower depths. Unless the excavated material is plastic or sticky, it is usually possible for the laborers to throw out material from trenches up to a depth of about 8 ft. Below this depth, it is advisable to arrange platforms (see Chapter IX) about 6 ft. below the surface of the ground, these platforms resting on the cross braces if the trench is sheeted, or on temporary braces where the trench is not sheeted. This platform should be sufficiently long to permit material to be thrown upon it by two excavators, one at either end, while one staging man should be able to keep the platform clear, casting the material well back from the edge of the trench. Such stages may extend entirely across the trench, but where trenches are wide enough to permit, it will be found convenient to build narrow stages onto which the men in the bottom can throw the excavated material from any points at which they may be working.

For trenches deeper than 14 ft. a second set of platforms or stages should be used, built about 12 ft. below the surface, and so arranged that two men shall throw from the bottom of the excavation onto the stage, and that the material shall be overcast by one man at each platform.

In constructing the platforms, a piece of plank may be placed on edge across each end, or along the side, to prevent the excavated material from falling upon the laborers below. "Square pointed" shovels should be used on the platforms, whereas the "round pointed" type are generally best for the work in the bottom. It is usually necessary to provide one man on the bank for every two in the trench to overcast the material thrown out after a depth of 5 ft. has been reached. The distance between platforms should be regulated according to the depth of the trench, rarely allowing it to exceed 6 ft. In some cases more rapid work will result from a somewhat closer spacing.

Material should be kept back from the edge of the trench a distance of 2 ft. where practicable, to allow room for the passing of foremen, inspectors, laborers, etc.; to prevent material from falling from the bank upon the laborers in the trench; to furnish space for the landing of the outcast material; and, where necessary, to furnish space for the handling of pipe, brick, mortar, concrete, lumber, and other materials to be placed in the trench, although it may be found more convenient to handle such supplies on the side not used for storing the excavated material. The side of the street opposite that on which the excavated material is placed should, however, be kept comparatively free from obstructions, so that, except in narrow streets, traffic may not be interrupted. The pipe, lumber, cement, sand, etc., which are required for use in the trench should be kept in neat piles either close to the trench line or at or near the curb line, so as to keep the street free from obstruction and to facilitate economic handling.

TUNNELING

Tunneling is a method of excavation often employed in the building of sewers, although relatively few large tunnels have been driven for this purpose. The methods used are those employed in all classes of tunneling and are described in a number of books on this subject, among which are "Tunneling" by Charles Prelini, "Modern Tunnel Practice" by the late David McNeely Stauffer, and "Modern Tunneling" by David W. Brunton and John A. Davis.

The relative cost of trenching and tunneling generally determines which method is to be adopted, although the latter may be undertaken to avoid interference with street traffic or tearing up a good pavement. Where the sewer is to be laid at a considerable depth, the danger of progressive settlement of the earth over the structure may be largely, if not wholly, prevented by building the sewer in tunnel.

Very small, shallow sewers are frequently laid alternately in short trenches and tunnels, the latter being of very small bore, often not more than 3 ft. in diameter. This method is rarely employed except in clay, hardpan or similar material, which is sufficiently cohesive to stand without timbering. The sections of trench, usually from 4 to 8 ft. in length, are sufficiently supported by the earth covering the tunnel sections which are usually of the same length as the trench sections. Where pipe must be laid during winter when the ground is frozen to a depth of 2 ft. or more, this process may prove economical by reducing the quantity of frozen ground to be thawed, picked or wedged out.

Depth at Which Tunneling May Prove Economical.—The depth at which tunneling may prove less expensive than trenching depends upon many local conditions and no specific rule of general application can be formulated for determining it. In soft ground, excavation conditions which tend to make trenching expensive also increase the cost of tunneling. In rock excavation on the other hand, this fact does not usually hold true and the cost of tunneling will be more uniform and the point at which it is exceeded by the cost of trenching will depend almost wholly upon the quantity of material to be handled.

As an illustration of the method of comparing the relative cost of trenching and tunneling, let it be assumed that sewers 3 ft. in diameter are to be built 25, 30 and 35 ft. deep, respectively. The minimum quantity of excavation, if built in tunnel, will be 1 cu. yd. per linear foot. The sewers, if built in trench, will involve the excavation of at least the quantities of earth, or rock, shown by Table 5.

TABLE 5.—QUANTITY AND COST OF EXCAVATION REQUIRED FOR BUILDING 3-FT. SEWER IN TRENCH

Depth of trench	25 Ft	30 Ft	35 Ft
If two sets sheeting are used, cu. yd. per lin. ft.	5.9	. . . .	. . . .
If three sets sheeting are used, cu. yd. per lin. ft	7.7	8 75	9.75
Cost per lin. ft. if two sets sheeting are required, at $1 per cu. yd.	$5 90	. . . . . .	. . . .
Cost per lin. ft. if three sets sheeting are used at $1, 1.25, and $1.50 per cu. yd., respectively	$7 70	$10 94	$14 63

Arbitrarily assuming further that the trenching, including timbering and backfilling, can be done for $1, $1.25, and $1.50 per cubic yard for the respective depths, it follows that the cost per linear foot will vary from $5.90 to $14.63, depending upon the number of sets of sheeting used and the depth of excavation. In other words, if tunneling is to be adopted, it must be estimated at less than $5.90 to $14.63 per cubic yard for the several conditions given.

In general, it is wise to consider the relative cost of trenching and tunneling when the depth of the sewer is to be over 25 ft.

In rare cases tunneling may afford a means of successfully doing work which could be conducted by trenching only at great expense and danger to life or neighboring structures, as where the sewer must be laid through very treacherous water-bearing, running sand or subaqueous ground. In such material, pneumatic tunneling affords a relatively safe and economical means of handling the work.

Tunneling in Different Kinds of Material.—Probably the simplest and easiest tunneling is in hardpan, dry clay or other earth, cohesive enough to retain its position, without caving, sufficiently long to allow laying the pipe or placing the masonry. In such cases timbering is not required and the heading may be cut out to the exact line of the masonry. The progress can be rapid and in some cases little, or possibly no, backfilling may be required. The cost of excavation will, of course, vary with conditions, but will probably not be less than $0.75 and may considerably exceed $1.50 per cubic yard, including cost of excavating shafts.

Difficulties are met when loose sand and gravel are encountered and recourse must be had to timbering and close sheeting, great care being taken to prevent material from "running" into the heading. The use of timbering increases the cost and the difficulties of maintaining correct alignment. The cost of driving such a tunnel will hardly be less than $3 in large tunnels and may reach $15 or $20 per cubic yard in smaller ones, and the quantity excavated will also be greater than when the excavation is in the more favorable material.

Unfortunately, most sewers are built below the natural water table, thus often greatly increasing the difficulties of tunneling. This ground water is handled in the same way as in trenching, but if the earth is of such a character that it tends to "run" when wet, the attendant difficulties will be increased and the rate of progress may be greatly reduced. Where the soil is very treacherous, or where the work is being done under a stream or body of water, it may be necessary to drive the tunnel under air pressure. A case of this class, carried out under the authors' direction in Worcester, was a tunnel about 6 ft. in diameter, lined with wooden segmental rings made in eight pieces, which accommodated a 32 × 42-in. sewer. A view of this work is given in Fig. 95. The air pressure required did not exceed 10 lb. per square inch and the earth excavated was fine sand. The cost of excavation was about $19.73 per cubic yard.

Since rock drills operated by compressed air became available and high explosives fired by electricity have been perfected, tunneling through rock has been greatly simplified and in fact is now subject to less uncertainties and difficulties than most soft ground tunnel work. This, however, is not true of tunnels driven partly in rock and partly in loose earth, where great trouble is sometimes experienced in keeping the roof and sides securely braced at all times so that the earth may not run.

Each blast is likely to blow out bracing, which is replaced with difficulty, often only to be blown out again. The cost of tunneling in rock may vary from $3 in large tunnels or those through rock which is very easy to excavate, to $15 per cubic yard in small tunnels, including shafts.

Lighting.—The best source of light is electricity, but even with it miners' lamps are desirable for the use of the miners and bracers. Where compressed air is used for drilling, it may be possible to get along with oil lamps and gasoline torches, although this is not to be recommended. If electric current is run into a rock tunnel, care must be exercised to prevent the premature firing of the dynamite by accidental contact of lead or fuse wires with lighting or power circuits. It is difficult, especially in small tunnels, to prevent the workmen from touching bare wires and rails so that high-tension currents are inadvisable. Circuits carrying 220 to 250 volts have been much used and have given satisfaction. Machinery wound for this voltage for use in mines and tunnels is readily obtained, as it is largely used on this class of work.

Ventilation.—There is little difficulty in providing suitable ventilation in rock or pneumatic tunnels, as the exhaust from the drills and the leakage from the headings are usually sufficient to provide ample change of air. In earth tunnels, on the other hand, there is seldom so convenient a supply of air and it is frequently necessary to install ventilating machinery and ducts. Sometimes, where pumping is required, this may be done by compressed air and the exhaust piped to the headings for ventilation.

Handling and Transporting Materials.—Methods of mucking and transporting materials must be worked out for each tunnel. In earth tunnels the mining and mucking proceed simultaneously and are usually suspended while the masonry is being placed. In rock tunnels it is often convenient to do the drilling and blasting during one shift and the mucking during the next.

If the tunnel is very long some means of transporting materials must be provided. Usually a track is laid and the loaded cars are pushed by workmen, drawn by mules or hauled by compressed air or electric motor cars. Fig. 14 gives two views of an electric car used by the authors in several small tunnels. An electric current of 220 volts was provided, being carried in by a small third rail, the return being through the rails of the track. The lighting current was taken from the rails wherever required.

The motor car hauled one or more flat cars on which were buckets loaded with the excavated materials. When the shaft was reached the buckets were hoisted by suitable machinery. The materials for the construction of the sewer were handled in the same way.

Shafts.—In very short tunnels work may be carried on from the

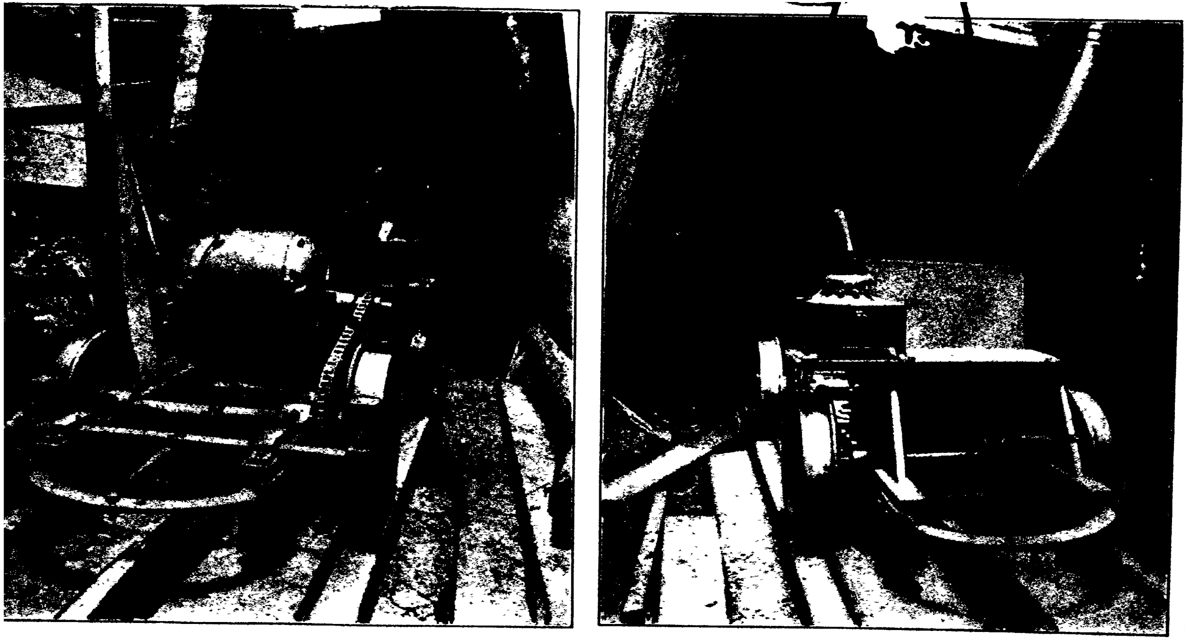


FIG. 14.—Electric locomotive used in sewer tunnels at Worcester.

(Facing page 64)

portals only, but where the tunnels are long, reasonable progress generally requires the sinking of shafts so that work can be carried on at a number of points. They are generally sunk on the line of the tunnel and are of suitable size to allow for the passage of men and materials and for such pipes, wires, ventilating flues, chutes and other accessories as may be required. As the line of the sewer is usually taken down the shafts by the surveyors, it is desirable to make them fairly long even on small work, a length of at least 8 ft. being desirable. In Louisville, where borings were made prior to letting the contracts, wrought-iron pipe casings were driven into the bore holes at proper points and capped, being left for use in transferring the line into the tunnel when required.

Shafts are excavated and sheeted in the same manner as trenches, except that it is advisable to make the bracing somewhat more substantial that it may withstand, without deformation, heavy pressures likely to be developed during the long time the shafts are to remain open.

Methods of Tunneling in Soft Ground.—Small tunnels are driven by excavating the whole section at one time, properly timbering it and proceeding with the excavation of another portion, or immediately lining it, in which case the excavation and lining proceed alternately, the one being suspended while the other is going on. In such cases it is advantageous to carry on work at several headings that the miners and masons may be economically employed at all times. This may also be accomplished by alternating shifts, the excavation being done on one shift and the masonry placed during the next.

Upon large tunnels, headings or drifts are often driven some distance ahead of the excavation of the whole section, the remainder of the work consisting simply of breaking in, or down, the earth or rock surrounding the headings. The term "heading" is frequently used upon small work as meaning the end of the tunnel in which excavation is being carried on at the time, but upon large tunnels, it more often refers to a small tunnel driven ahead of the main tunnel. Prelini, in "Tunneling," after discussing the confusion which has arisen over the use of the terms "heading" and "drift," suggests:

> "For the sake of distinctness of terminology, it seems preferable to call the passage a heading when it is located at the top of the profile, and a drift when it is located near the bottom."

The problem of timbering the tunnel is generally the governing consideration in the selection of a method of tunneling, although drainage and prospecting to determine the character of materials to be traversed by the main tunnel may be important factors. Prelini describes four general methods of driving large tunnels as follows:

> "(1) Excavating the tunnel by beginning at the soffit of the section, or by the Belgian method, is the method of tunneling in loose soils most

commonly employed in Europe at the present time. It consists in excavating the soffit of the section first; then building the arch, which is supported upon the unexcavated ground; and finally in excavating the lower portion of the section, and building the side walls and invert.

"(2) In excavating tunnels along the perimeter an annular excavation is made, following closely the outline of the sectional profile in which the lining masonry is built, after which the center core is excavated. In the German method two drifts are opened at each side of the tunnel near the bottom. Other drifts are excavated, one above the other, on each side to extend or heighten the first two until all the perimeter is open except across the bottom. The masonry lining is then built from the bottom upward on each side to the crown of the arch, and then the center core is removed and the invert is built.

"(3) This method, as its name implies (tunnels excavated in the whole section—English and Austrian methods), consists in taking out short lengths of the whole sectional profile before beginning the building of the masonry. In the English method the lengths of section excavated vary from 10 ft. to 25 ft. The masonry invert is built first, then the side walls, and finally the arch. The excavators and the masons work alternately, the excavation being stopped while the masonry is being built, and *vice versa*. The Austrian method differs in two particulars from the English; the length of section opened is made great enough to allow the excavators to continue work ahead of the masons, and the side walls and roof are built before the invert.

"(4) The Italian method is very seldom employed on account of its expensiveness, but it can often be used where the other methods fail. It consists in excavating the lower half of the section, and building the invert and side walls, and then filling the space between the walls in again except for a narrow passageway for the cars; next the upper part of the section is excavated, as in the Belgian method, and the arch is built; and finally the soil in the lower part is permanently removed."

Methods of Tunneling in Rock.—In full rock headings, there is usually no necessity for timbering, although some rocks are so soft and seamy that shoring is required. The invention and development of rock drills, high explosives and methods of electric firing have greatly simplified rock tunneling during the last half century, so that now the ordinary rock tunnel presents a far less difficult problem than many of the tunnels which have to be driven through soft ground.

As in soft ground tunnels, in some cases headings, or drifts, are driven ahead of the full section of the tunnel for the purpose of determining the character of the rock through which the tunnel must pass. In most large rock tunnels, such passages are driven at least a short distance ahead of the full section of the tunnel to aid in breaking down the surrounding rock. These drifts are usually in the neighborhood of 6 or 8 ft. in diameter. In small tunnels, it is customary to drill, near the center of the tunnel, three or four holes directed along converging lines toward the apex of a pyramid. These holes are fired together, constituting the cut-shot. After these holes have been fired, the breaking-in holes which surround them are fired, upon small work usually all at one time and upon larger work in relays. The development of the "delay" fuzes has greatly facilitated this class of work as it permits the firing of the cut-shots first and breaking-in shots successively thereafter, without the necessity of clearing the tunnel of fumes and rewiring the holes.

Placing Masonry.—The placing of masonry in tunnels, and especially in small tunnels, involves difficulties not ordinarily encountered upon similar work in trenches. Usually, the entire space between the inside profile of the structure and the excavation must be filled with masonry. Upon small work, the masonry of the upper portion of the sewer must be placed from the end, necessitating the use of relatively short centers and forms.

Upon most sewer work, the concrete or mortar is prepared on the surface of the ground, and taken down the shaft and into the tunnel when ready to be placed.

PUMPING, BAILING AND UNDERDRAINAGE

One of the most variable and oftentimes perplexing problems which has to be overcome in sewer excavation is the removal of the ground water which finds its way into the trench. Its quantity varies from an almost negligible amount, which may ooze or percolate into the trench from very compact soils, to an almost constant flow from the free and water-bearing gravels. The method adopted to care for and remove the ground water will vary according to its quantity and with the character of the soil in which it is found.

Where the amount of water encountered is slight it can frequently be allowed to gather or flow into little sumps, from which it can be removed by bailing.

The most common method of disposing of water where it accumulates in moderate quantities is by means of a diaphragm suction pump operated by hand and capable of handling from 30 to 50 gal. per minute, when lifting it from a depth of about 16 ft., the maximum lift depending in great measure upon the condition of the rubber diaphragm and valve. Power diaphragm pumps of a capacity of from 50 to 100 gal. per minute, driven by gasoline engines mounted upon trucks, are now available.

Diaphragm Pumps.—These are made either as suction pumps or as force pumps. In the former case the water is discharged freely over a lip on the side of the pump body and in the latter it is forced through a pipe. These pumps are made in several sizes, ranging in rated capacity from 1800 to 6000 gal. per hour, under most favorable conditions. The size most commonly used is that requiring a 3-in. suction hose and weighing about 185 lb. This pump operated by one man at a rate of 30 strokes per minute will deliver about 30 gal. per minute. Upon very shallow work a single length (12 ft.) of hose is ordinarily used. A variety of strainers are on the market and it is well to select that having the largest holes which it is safe to use with the water to be pumped, since fine holes increase the frictional resistance. The cost of a pump, two lengths of hose and a strainer will be from $50 to $75.

The life of the hose, which is fully as expensive as the pump, may be greatly prolonged by using it with care, not allowing it to become kinked, rubbed on the bank, or cut. Cotton-covered or jacketed hose may be obtained at small extra expense.

While with a perfect pump and suction hose it may be possible to lift water from a depth of 25 or 26 ft., it is generally not practicable to use this pump for lifts of over 20 ft. at sea level, and even at such a lift it is necessary to use several men on the pump.

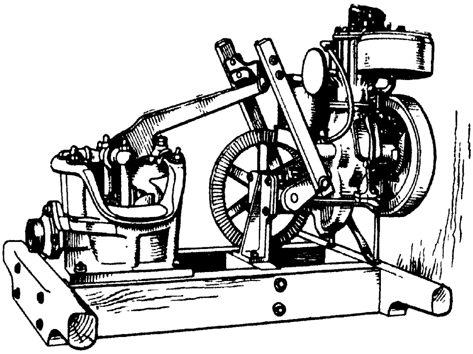


Fig. 15.—Gasoline-driven diaphragm pump (Edson).

In Fig. 15 is shown an Edson diaphragm pump connected to a gasoline engine. The outside dimensions of the wooden base are 3 ft. 9 in. by 3 ft. It can be easily carried about by four men or it can be mounted on a 4-wheel hand truck. It is stated that a 10-hr. continuous run will require approximately 2 qt. of gasoline, and that the outfit will handle 6000 gal. an hour. The prices of complete outfits vary from $100 to $160.

Centrifugal Pumps.—These can generally be used to good advantage where large quantities of water are to be handled, and if a pump with an open impeller is used, it will handle very dirty water without much injury in most cases. Table 167 and the description of centrifugal pumps in Volume I make any notes on the subject unnecessary here. Most of the pump makers supply outfits made specially for construction purposes. These consist of the pump and a direct-connected electric motor, or steam or gasoline engine, mounted on skids or on a wheeled truck.

Where a large volume of water must be handled for a long time, as in tunneling, and where the lift is considerable, a high-grade plant designed to fit the conditions will often prove more economical than one of the less efficient but also less expensive outfits for general service. If such an expensive equipment is used, particularly if turbine pumps are employed, attention should be paid to preventing materials from entering the pump which will interfere with its operation, and a sump in which a sand-catching chamber is incorporated may prove desirable.

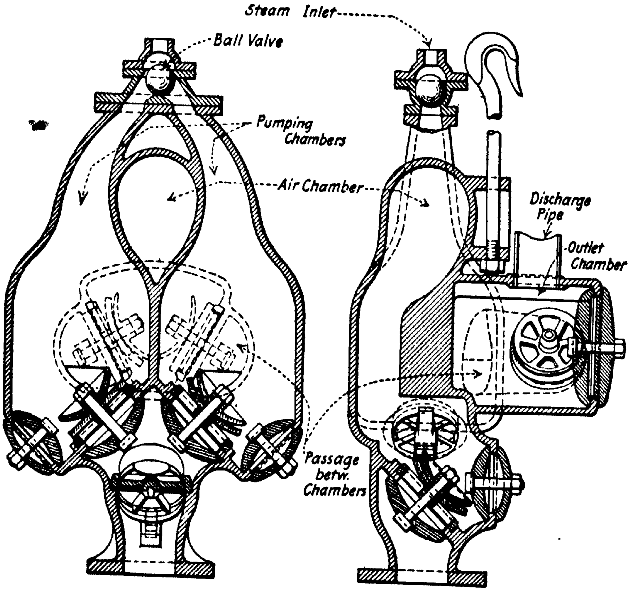
Where the drainage of a trench can be accomplished through underdrains discharging into a sump which can be kept in service for a considerable time, it is often advisable to install a centrifugal pump at the sump, but the low lift and dirty water to be handled by such an outfit make high efficiency less desirable than reliability.

Reciprocating Pumps.—These are not well adapted to the handling of water under the conditions usually existing about sewer trenches, because of the grit likely to be carried by the water, which cuts the plungers and valves. In some cases, however, the water may be relatively clean and if a supply of steam or compressed air is available, a reciprocating pump may be set up and operated with very little attention and often at small expense. Where such pumps are used in connection with driven wells to lower the ground water which would otherwise flood a trench or pit, it is usually necessary to place on the suction line a sand-catcher, such as is employed in water-works plants using a well supply. Outside-packed plunger pumps of the low-pressure type are suited for this service and are better than the heavier patterns for 250 lb. pressure. Piston pumps are unsuited for construction purposes except in the very rare cases where clear water is to be handled.

Steam Vacuum Pumps.—Three types of steam pumps of a special class are largely used on construction work where very dirty water must be handled and the position of the pumps must be changed frequently. The first of these to come into general use was the pulsometer, which was followed by the Nye and Emerson types.

The pulsometer has a body with two bottle-shaped pumping chambers, Fig. 16, with their necks communicating at the top, each opening into an outlet chamber through a check valve. An air chamber connects with the suction inlet and cushions the incoming pulsations. Near the top of each pumping chamber is an air check valve opening inwardly, which admits a small quantity of air automatically at each pulsation at the moment the vacuum is formed. This layer of air cushions the inrushing water and forms an air piston between the steam and water, preventing the former from being condensed at the beginning of the stroke.

Steam from the boiler is piped to the inlet at the top and from there is turned to the right or left chamber according to the position of the ball steam valve, which is free to roll to either side, forming a steam-tight joint with whichever seat it rests upon. In the position illustrated the steam would pass to the left-hand chamber, which may be assumed to be full of water. The pressure of the steam forces the water through a passage between the air and outlet chambers and a check valve into the outlet chamber and thence into the discharge pipe. When the water falls to the level of the opening into the outlet chamber, the water and steam become churned up together and the latter is condensed. This forms a partial vacuum in the left-hand chamber, which, assisted by a slight upward pressure in the right-hand chamber, immediately pulls the ball valve over to the left-hand seat, shutting off the steam supply. The vacuum in the left-hand chamber then draws up a new charge of water through the suction pipe, and while it is filling, the right-hand one is emptying, bringing about the conditions that existed at the beginning of the cycle.

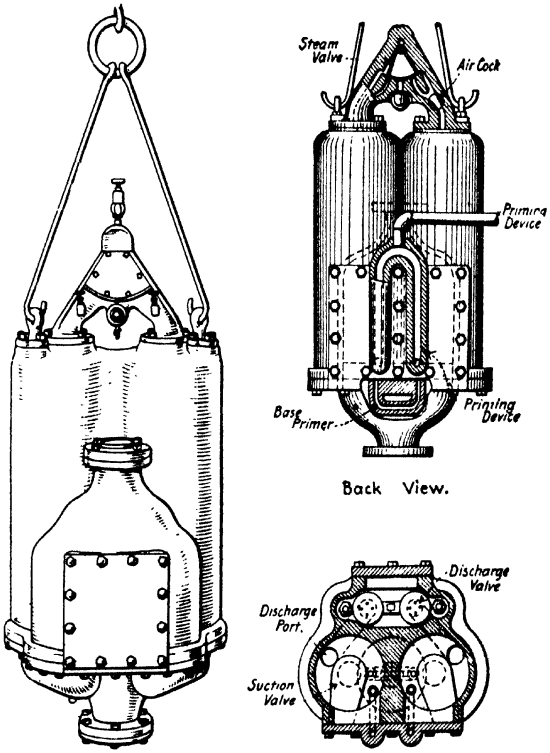


Transverse Section. Longitudinal Section.

FIG. 16.—Sections of the pulsometer.

Table 6 gives the more important dimensions of the sizes now (1914) made; the manufacturer, the Pulsometer Steam Pump Co., New York, states that the capacities are underrated for most cases, particularly with a short suction and high steam pressure.

The Nye steam vacuum pump, made by the Nye Steam Pump & Machinery Co., of Chicago, is the result of an evolutionary process beginning in an 1869 patent. The "new model" shown in Fig. 17 was patented in 1909. The steam valve is hollow and it offers very little resistance to motion. The two air valves are located so as to admit a piston of air between each charge of steam and the water on which it acts. In starting the pump both the steam and air valves are closed.



Back View.

Front View. Pump Base.

Fig. 17.—The Nye pump.

TABLE 6.—CAPACITIES AND DIMENSIONS OF PULSOMETERS

Trade No.	2	3	4	5	6	7	8	9	10
Gal. per min.									
25-ft. head...	20	60	100	180	300	425	700	1000	2,000
50-ft. head. .	17	50	80	160	265	375	625	900	1,800
75-ft. head.	13	38	65	115	200	275	450	650	1,400
Weight, lb.	95	140	295	430	570	745	1,375	2,100	3,800
Height, in... . .	25	27	33	38	43	49	61	72	88
Floor space, in....	$\frac{14}{13}$	$\frac{17}{11}$	$\frac{18}{19}$	$\frac{21}{22}$	$\frac{23}{24}$	$\frac{28}{26}$	$\frac{32}{33}$	$\frac{38}{36}$	$\frac{52}{42}$
Boiler h.p.	4	5	6	10	12	15	25	35	70

Then the valve on the steam pipe at the boiler is opened wide, after which the steam globe valve at the pump is quickly opened, allowed to remain open 3 or 4 sec., and is then quickly closed, this being repeated after the steam has remained off during 4 or 5 sec. This manipulation is repeated until a click of the hollow steam valve of the pump indicates that the pump has caught its suction. The steam valve is then left half or three-quarters open and the air valves are adjusted until the pump is working satisfactorily. The shorter the suction, the greater the quantity of air required. The suction valves are of the clack type, the discharge valves of the ball type. The method of operation is, in general, like that of other types of vacuum pumps.

TABLE 7.—CAPACITIES AND DIMENSIONS OF NYE PUMPS

Trade No.	2	3	4	5	6
Gal. per min.					
50-ft. head..	200	300	500	800	1000
100-ft. head.	100	200	400	600	800
Weight, lb...	550	900	1600	2300	2800
Steam pipe, in....	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
Suction pipe, in....	3	4	5	6	7
Discharge pipe, in......	2	3	4	5	6
Boiler h.p.[1]	15	20	25	30	40

[1] This boiler capacity is suited for a 50-ft. lift. Two-thirds as much capacity will answer for 25 ft. and about 33 per cent. more will be needed for 100-ft. lift.

The Emerson pump, made by the Emerson Steam Pump Co., of Alexandria, Va., has two chambers, Fig. 18, each with a disk suction valve at the bottom and a disk discharge valve opening into a small chamber from which the discharge pipe runs. On top of each chamber is a flange with a baffle plate cast on its lower side opposite the port through which steam enters the cylinder. The baffle plate distributes the steam evenly and prevents any agitation of the surface of the water in the cylinders. A condenser nozzle in each chamber is connected with

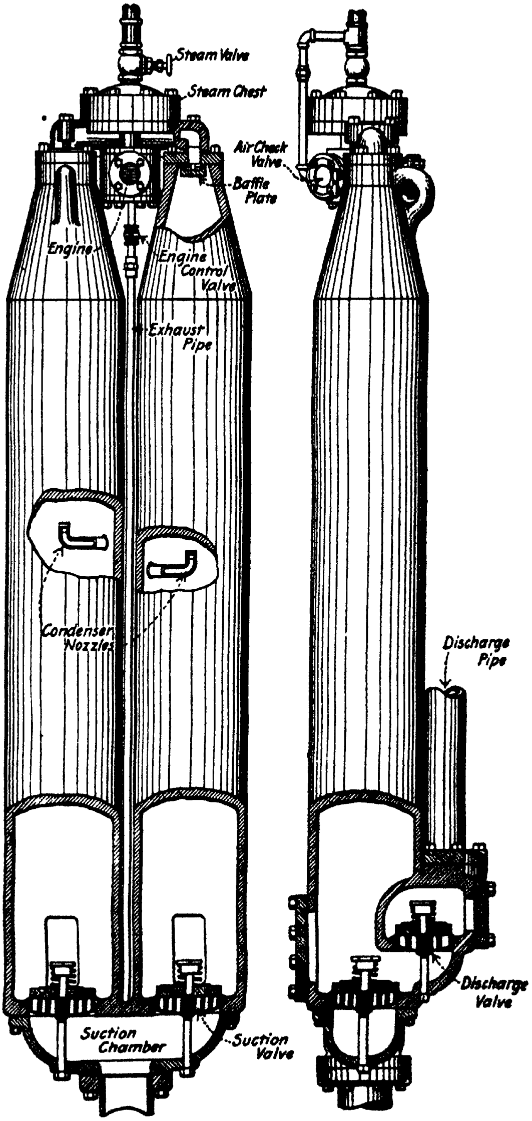


Fig. 18.—The Emerson pump.

the bottom of the opposite chamber by an extra heavy pipe into which a check valve opens upward. As the pressure in the chambers alternates, sufficient water will be injected through each nozzle into the opposite chamber to condense the steam in it and promptly form a vacuum. A small air check valve attached to each chamber at the top and opening inward admits a small quantity of air while the chamber is filling with water, to act as an air cushion or piston, as in other types of steam vacuum pumps. The globe valve just above the steam chest is used to regulate the amount of steam to the conditions; another valve for starting and stopping must be placed between the boiler and pump.

The steam chest has two ports, one leading to each chamber. A flat rotary slide valve, entirely enclosed in the steam chest, admits steam through these ports to the two chambers alternately. This slide valve is driven by a small three-cylinder engine rigidly attached to the lower side of the steam chest.

The engine crank shaft extends into the steam chest in the center of the bearing around which the slide valve rotates, and a positive connection is made between the engine and the valve by steel and bronze gears, so arranged that the engine will run faster than the valve. The motion of the engine is controlled by a valve on the exhaust pipe passing down from the engine to the suction chamber, where the exhaust steam is condensed.

TABLE 8.—CAPACITIES AND DIMENSIONS OF EMERSON PUMPS

Trade No.	1	2	3	4	5	6	A	B	C
Gal. per min[1]	225	415	725	1,200	2,100	3,275	100	150	200
Weight, lb	950	1,375	1,900	3,100	4,400	5,400	219	290	410
Height, in.	98	104	113	127	132	135	47	47	47
Breadth, in	17	22	26	30	44	52	15	18	21
Width, in.	18	21	24	28	33	37	11	11	14
Steam pipe, in.	¾	1	1¼	1½	2	2½	½	¾	¾
Suction pipe, in.	3	4	5	6	8	10	3	4	5
Discharge pipe, in.	2½	3	4	5	6	8	2½	3	4

Note.—Nos 1 to 6 are two-cylinder pumps and Nos. A to C are single-cylinder pumps.

[1] Capacities given in the table are calculated for a lift of 20 ft These diminish at the rate of about 4 *per cent for every 10 ft.* additional head, for Nos 1 to 6, and at the rate of 6 per cent for every 10 ft. additional head, in the case of Nos. *A* to *C* The maximum head *for two-cylinder pumps is 150 ft.* and *for single-cylinder pumps 100 ft*

In starting up, the air check valves are opened, and the steam valve is opened for 5 or 6 sec. and then closed. The steam expels the air from the cylinders and condenses, forming a partial vacuum which causes water to rush toward the suction chamber. The engine is started by opening an exhaust valve (not shown in the illustration) which opens outside. After the water has been worked out of the engine and it exhausts steam, the outside exhaust valve is closed and the engine-control valve is opened about half a turn. The steam valve is next opened two or three turns and the engine-control valve manipulated until the pump runs smoothly and quietly. If the suction valves hammer it is because either the steam valve has not been opened enough or the engine-control valve has been opened too much.

The same company also makes a smaller single-cylinder steam vacuum pump, called the Emerson Junior, which utilizes a balanced valve to control the operating cycle.

Underdrains.—Underdrains may be divided into two classes, construction underdrains, which are put in simply to facilitate the building of the sewer and are generally abandoned upon its completion; and permanent underdrains, which are made a part of the drainage system, and are provided with permanent outlets. The latter are particularly serviceable where a sanitary system of sewers alone is provided, as they lower the elevation of the water table, thus making it possible to provide dry cellars which would otherwise be wet, and often prevent much infiltration into the sewers. As such drains are laid immediately below the sewers, they are likely to receive the leakage from the latter, if there is any, and care should be taken to prevent the contamination of water supplies by the discharges from such underdrains.

Obviously the joints in underdrains must be left open for the admission of ground water, and in some places much trouble has been experienced with the growth of roots in the pipes, and also with deposits of fine sand and earth, carried in through the joints with the water. In some places the sewer manholes have been provided with chambers through which access may be had to the underdrains, for purposes of inspection, flushing and cleaning, as illustrated by Figs. 220 and 249, Volume I. In general less trouble with the growth of roots has been experienced in underdrains than in sewers, as the latter are usually nearer the surface and contain many joints which are not sufficiently tight to prevent the entrance of roots, although in some places the reverse is true, more trouble being experienced with underdrains. Little can be done to prevent the entrance of roots into the underdrains, but if they are thoroughly well laid, as described later, there should be relatively little difficulty from the admission of dirt.

If good work is to be done, it is absolutely necessary to have a dry trench. Joints made of cement must not be submerged or exposed to running water until the cement has had ample time to acquire its final set. It is usually safe to allow the water to come in contact with mortar after it has had 24 hours in which to set.

It is claimed that certain plastic jointing materials may be poured successfully under water. While the authors have seen a few joints successfully poured in this way, where care was taken to pour the fluid jointing material into one side of the bell, thus allowing water to flow out the other, they believe the practice to be dangerous, as there is difficulty in getting good work under such conditions. While concrete can be placed under water, under many conditions, this should not be attempted upon ordinary sewer construction, where the thickness of the concrete is relatively small, and where the entire section should be in excellent condition and thus available for the purpose for which it was designed.

Where considerable water finds its way into the trench it is generally wise to provide a construction underdrain, through which the ground-water may flow to a gravity outlet or to a pump well provided for the purpose.

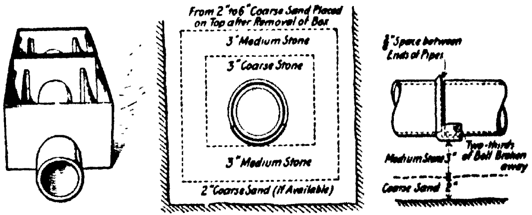
The method of constructing underdrains depends much upon the material through which they are to be laid. If in rock, there is little danger of the entrance of sand or earth which will cause clogging, and it is obviously desirable to reduce to a minimum the quantity of rock excavated. In gravel there may be little danger of the entrance of fine material, and it may be necessary only to excavate the trench, lay the pipe, and refill with a small quantity of screened cobbles or crushed stone. The greatest difficulty is encountered where the drain is to be laid in fine water-bearing sand. Here great care must be taken in laying and surrounding the pipe with gravel and sand, if the admission of fine material is to be prevented. In many instances underdrains have been laid only to be completely clogged within a few hours. The authors have laid many miles of underdrains in such trenches, by surrounding the pipes with screened cobbles or broken stone, sometimes even covering the entire bottom of the trench with gravel to a depth of 2 or 3 in.

In an article on the "Maintenance of the System of Separate Sewers at Newton, Mass.," by Stephen Childs (*Jour. Assoc. Eng. Socs.*, Jan., 1899), the method of laying underdrains in Newton is described as follows:

> "Under all of our sewers (with the few exceptions where it was definitely known that the level of the ground water was much lower than the sewer grade) an underdrain has been laid. The size necessarily varies, our largest being 18 in. under one of our main sewers, and 4 in. being the minimum. The underdrain pipes are surrounded by screened gravel, and the whole is covered with a layer of bagging to prevent the clay from working down into the drain. This bagging does not rot until the soil above has become so compact that there can be no tendency for it to settle into the drain. The underdrains are so designed that they discharge at frequent intervals, either into convenient brooks or the Charles River; and as they are inspected and kept free, together with the system of sewers, they furnish a continuous outlet for ground water, and are therefore of great advantage, especially in those parts of our city where the soil is compact clay and the level of the ground water high."

Where underdrains are to be laid in bad material or are to be a part of the permanent drainage system, it may be necessary to adopt the method of construction used for the building of underdrains in sand filter beds, illustrated by Fig. 19. Where the material in which the drain is laid is very fine, it is usually necessary to use two or three grades of gravel and a relatively coarse sand, as indicated by the sketch. The gravel should be so graded from coarse to fine that the finer material overlying the coarser will not penetrate it. By this method underdrains have been laid in relatively fine sand and have been kept open for many years, in spite of the fact that large quantities of water filtered into them continuously.

Underdrains may discharge into rivers, brooks or sewers, or into pump wells. Such wells may be located directly on the line of the sewer or at one side of the trench. The latter location is preferable in many cases as it is possible to lay the sewer past the pump well, thus completing it before closing the drain and filling the well. In some cases where the slope will permit, it is desirable to turn the underdrain up and allow it to discharge into the sewer. In such cases, unless it is a storm drain or combined sewer, it is afterwards necessary to plug the underdrain, which is sometimes a matter of considerable difficulty. One method of accomplishing this is to insert into the underdrain, or the well into which the drain discharges, and build securely into the masonry, an iron pipe provided with a thread at its upper end, this pipe terminating from 4 to 6 in. below the water line of the masonry sewer. Onto this pipe is screwed a length of iron pipe through which concrete is forced into the well or underdrain, thus completely or partially stopping the flow of water. The upper pipe is then removed and a pipe cap is screwed onto the pipe previously built into the masonry. This makes a tight joint and the concrete or brick work of the sewer may be completed over it.


From 2" to 6" Coarse Sand Placed on Top after Removal of Box
3" Medium Stone
3" Coarse Stone
3" Medium Stone
2" Coarse Sand (If Available)
⅜" Space between Ends of Pipes
Medium Stone 3"
Two-thirds of Bell Broken away
Coarse Sand 2"

Mold for Placing Material.

Filling around Underdrains.

FIG. 19.—Grading material around underdrains.

Occasionally, underdrains are laid long distances in water-bearing gravel and collect very large quantities of water, which may be used to advantage. In one or two instances, the authors have extended such underdrains into wells from which large supplies of water were pumped for condensing purposes. In Baltimore, Md., large quantities of water collected by underdrains are used for condensing at the sewage pumping station. Ground water is particularly good for this purpose as it is always relatively cold.

Where underdrains are to have permanent outlets great care should be taken to so build them as to prevent the water from carrying fine sand or clay into them, thus eventually undermining the sewers and possibly other structures, as well as clogging the underdrains.

Method of Cleaning Underdrains.—Notwithstanding the considerable variety of precautions which may be taken to prevent sand from entering construction underdrains, experience teaches that it does often enter and it is desirable to have ready a means of agitating the sand so that the water flowing in the underdrain may carry it to the pump. The means usually adopted for such agitation is to thread a manila rope through the bore of the underdrain, as it is laid. This may be pulled back and forth, thus stirring the sand and preventing its sedimentation.

The rope should be of hemp, about 3/4 in. in diameter, having a loop at its forward end which should be drawn ahead as fast as the pipe are laid. It should be wound upon a reel suspended in the last manhole, and should pass through a snatch-block so arranged that the rope may enter the lower end of the underdrain without disturbing the pipe and thus avoid the necessity of keeping a man at the lower end to feed the rope in as the work progresses. If the rope fails to stir the sediment sufficiently a chain may be drawn back and forth through the pipe, until it is cleared.

Method of Handling Excavation in Advance of Underdrains.—The difficulties experienced with underdrains filling up with sand are due in great measure to the sand which enters the pipe at its upper or free end. Sand does not, or at least should not, enter the pipe along its length, provided the underdrain has been properly constructed. It is difficult to prevent the sand entering the pipe at its upper end, as the very process of excavation keeps the sand stirred, and with large volumes of water flowing directly to the free end of the pipe the sand is carried along with the water into the pipe.

As the construction in the trench of sumps in which the sand may deposit, and from which the clearer water may flow directly into the free end of the underdrain, greatly delays the progress of laying the underdrain, it is generally considered better practice to keep the drain laid close to the excavation.

In some cases it may be advisable to handle the water which gathers within the portion of the trench under excavation by means of hand pumps, raising it to the surface, unless the depth is such as to prohibit this. Handled in this way, a comparatively short length of trench bottom should be worked at one time, and the underdrain should be laid as fast as a portion of the bottom is ready, its upper end being continuously protected by means of a substantially constructed strainer so arranged as to keep out the fine sand. One or more hand pumps should remove the sand-ladened water which finds its way into this short portion of the trench, while other pumps should take care of the water that gathers in advance of this portion of the trench. In this manner the portion of the trench ready for the sewer is kept dry and the danger of clogging the underdrain is greatly reduced.

SETTLEMENT OF ADJACENT STRUCTURES

Frequently following or during the construction of sewers, structures or buildings adjacent to the line of the sewer are found to have settled. There are a number of different conditions which may be responsible for this. The settlement of pipes, conduits, pavements, curbing and sidewalks along the street in which the sewer is constructed may be due to the caving of the banks of the sewer trench, to the slow running of dry sand or gravel through the joints of the sheeting, or to the carrying of sand into the trench by the water flowing through the cracks in the sheeting or from underneath.

The settlement of adjacent buildings is due to the movement of the strata which lie beneath their foundations. This movement is either due to the drainage of water from them, thus causing them to subside or shrink, or else to a horizontal movement of a portion of the sand and the settlement of the balance with its superimposed load, owing to the reduced pressure within the trench. There have also been cases where settlement of buildings has been due to the movement of inclined, wedge-shaped masses of rock. Such was the case in 1902, when buildings on Fourth Avenue, New York, were damaged during the construction of the Rapid Transit Subway.

To prevent such settlement, the construction should be watched with great diligence. Where sand is finding its way in considerable quantities between the sheeting planks, greater care should be taken in placing and driving them, while the existing joints should be stuffed with oakum, hay or other material, and boards or planks nailed securely over the larger openings. In some cases it may be necessary to resort to the use of tongued and grooved timber, although this is not usually advisable.

Where water finds its way into the trench between or below the sheeting planks, frequent observation should be made to determine the presence of sand in the flowing water. If this water is allowed to carry sand with it for a considerable time, large voids may be formed behind the sheeting into which the superimposed soil may slide, thus causing damage to adjacent pipes, conduits, curbings, and possibly to

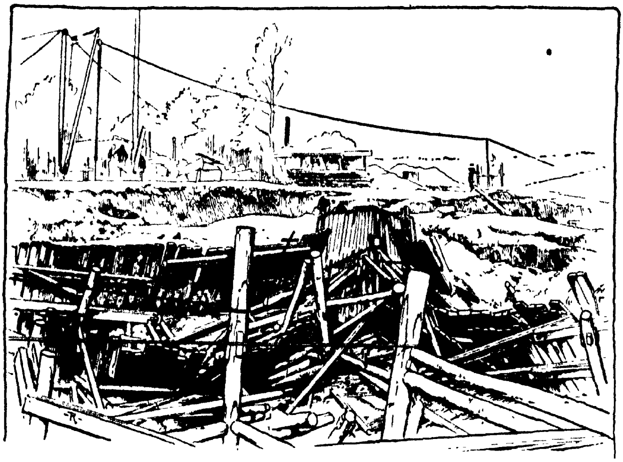


Fig. 20.—Interior of pit wrecked by flow of sand.

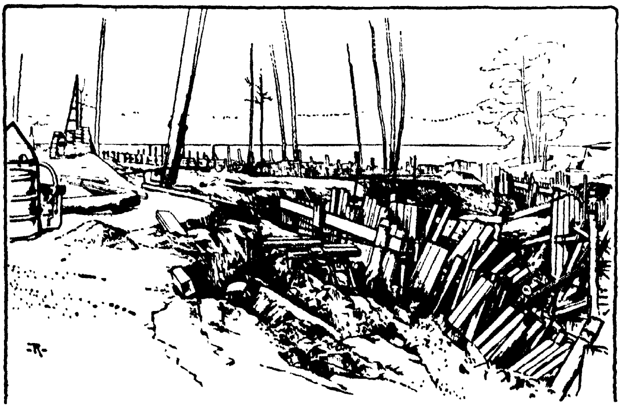


Fig. 21.—Exterior of pit wrecked by flow of sand.

buildings. When such slides occur, damage may result not alone to the adjacent structures and buildings but the sudden blow of the falling material against the sheeting may break braces and walings and force in the sheeting, destroying the trench for a considerable distance.

The effect of the unchecked flow of sand is illustrated in Figs. 20 and 21, which are views of an excavation for a pit for the construction of a pumping station at New Bedford, Mass. Here the sand was allowed to flow with the water for a number of weeks before the slide actually occurred.

The boiling of quicksand in the bottom of the trench, which is usually due to the relieved pressure, and the horizontal flow of sand from the quicksand stratum must be watched with great care. At such times the sheeting must be driven down on both sides of the trench considerably in advance of the excavation, thus tending to intercept the horizontal flow of the sand. The depth of the driving will depend on the thickness of the quicksand stratum, head of water in the sand and many other conditions.

Where such conditions are anticipated and in all cases where encountered, measurements and observations should be made carefully from which the exact condition of the adjacent structures before and after the completion of the work may be clearly shown. Such information should include the taking of exact elevations at several points on the structures, such points being accurately and fully described so that there may be no doubt that subsequent levels were taken at exactly the same points. Photographs should be taken and notes made of the exact time at which this was done and of the exact location of the camera. Measurements showing the relation of the front and sides of the buildings to true vertical planes should be made. Such measurements should be made in advance of any settlement for comparison with later measurements, from which the effect of unequal settlement may be shown. Such measurements should be made with a transit in perfect adjustment, set in the plane of the front or side of the building, or a plane parallel to it, and at such a distance from it that the entire height of the building may be brought within the range of the transit. Offsets from the plumb line to the face of the building may then be taken by means of a graduated steel straight-edge upon which is mounted a spirit level and a target rider which may be set by the transitman, accurate and clear descriptions of the points to which the offsets are taken being carefully and permanently recorded. Accurate levels should be taken along a given course of masonry near the surface of the ground, and upon window and door sills, from which the extent of the settlement, if any, may be determined.

CHAPTER IV.

MACHINERY FOR TRENCH EXCAVATION

Where trenches are narrow and shallow, hand excavation is generally more economical than the use of machinery. The depth at which mechanical excavation has an advantage depends upon many local conditions, and no definite rule can be given for determining it. The types of machinery most commonly used require trenches to be at least 3 ft. wide, and such machines are seldom put on trenches unless they are at least 12 ft. deep, except where there are traffic conditions which make it necessary to confine the work to narrow limits, which can be done much better with machinery than by hand excavation. In the middle and western states the soils often lend themselves to the use of machines of the Austin, Buckeye and other types, either bucket or breast wheel, and many trenches 22 and 24 in. wide and 6 ft. and more deep are thus dug. There seems to be a feeling that for less than about 6 ft. depth there is no great saving unless labor is scarce or very expensive. Under the latter conditions, one machine may do the work of 100 to 200 men per day. These machines are particularly adapted for use in soils like loam and soft sandy clay, which do not require close sheeting or heavy bracing. They have been used successfully, however, in heavy material like shale and hardpan. Pipe lines across trenches seriously interfere with their use, but in some cases it may be more economical to tear out such pipes with the machine and replace them later than to forego its use.

With the ordinary hoisting machinery, the cost of picking and shoveling the earth in the bottom of the trench is usually the same, whether a trench machine is used or the work is done by hand. To arrive at the comparative costs of hand work and that type of machine work, then, it is only necessary to compare the cost of staging and overcasting the excavated material and shovelling it back into the trench, with the cost of operating a machine, including labor, fuel, rental and all incidental expenses. When these two charges balance each other, it may be wise to adopt some sort of a trench machine as it is much more convenient and does not usually constitute as great an obstruction in the street. It is different with digging machines, for they require little labor and the decision to install them should depend largely on the supply of labor and their cost. Due regard, however, should always be given to the probable quantity of work to be done. It is not advisable to secure and use a machine for the sake of a very short piece of work, as the cost of unloading and erecting the machine, taking it down and re-loading it on the car, together with freight charges, is so great that it may prove a source of expense rather than of economy.

A number of machines have been designed expressly for use in excavating trenches, some for the actual digging of trenches; others built primarily for other kinds of excavation have been adapted to trench work so that they may be used to advantage under certain conditions. It is not the intention to describe all the machines which have been used for excavation of trenches, but only those which are most commonly used upon sewer work and a few of the larger machines which have been adapted for trench work and may be used to advantage upon some of the larger excavations.

Among the different types of machines which are available for trench work may be mentioned machines in which buckets are raised and lowered by means of cables, such as the ordinary cableway and the Carson, Potter and Moore trench machines; trench diggers like the Buckeye Traction Digger; the steam shovel with or without an extra long dipper arm, and either moved on standard gage tracks laid in the bottom of the trench or carried on tracks or traction wheels upon the surface of the ground; clam-shell and orange-peel buckets operated by derricks or locomotive cranes are also useful upon large work and wide trenches, and scrapers drawn by horses or mules, operated by derricks or by means of hoisting engines and cables, have been used to a limited extent upon sewer work.

Carson Trench Machine.—The Carson trench machine was designed by Howard A. Carson and first used upon work in the vicinity of Boston, Mass. It was designed especially for sewer trenches and is particularly well adapted to this class of excavation. It consists of a set of trestles tied together by connecting rods at the bottom and girders at the top. the whole being moved along a track laid on the surface of the ground. Attached to the girders is an iron track upon which travelers carrying the buckets are drawn forward and backward by means of two ropes operated by a double-drum hoisting engine, as shown in Fig. 22. The engine is carried upon a bed or car which rolls along the rails of the lower track. The drums of the engine are placed forward in the direction in which the work is to progress. The head rigging which is bolted to the engine bed projects forward a short distance to carry the blocks through which the ropes run from the drums to the rear part of the machine. The trestles in the rear of the engine bed are made in the shop and are set up individually. The first trestle when erected is attached to the engine bed and head rigging by means of two connecting bars, one on each side immediately over the rails of the bottom track, and a girder at the top which is fastened at one end to the trestle and at

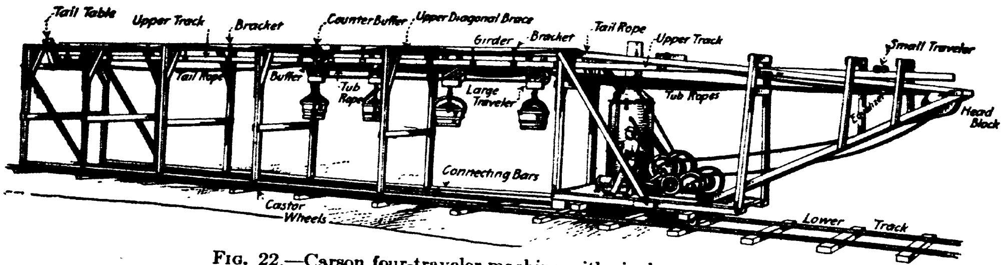


FIG. 22.—Carson four-traveler machine with single upper track.

A standard machine of four travelers has twelve trestles in the rear of the engine, although only six trestles are shown in this illustration.

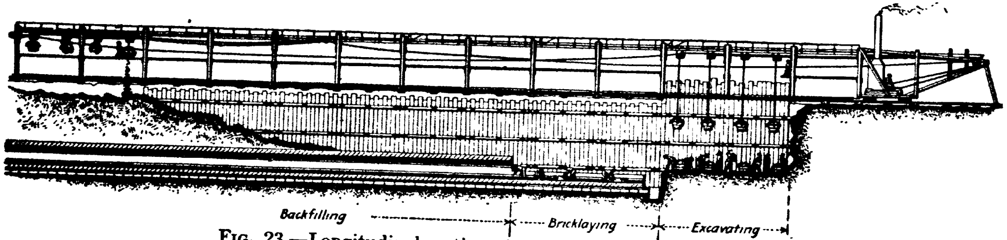


FIG. 23.—Longitudinal section of a sewer trench with machine.

the other to the head rigging. In erecting, work is begun at the engine bed and proceeds toward the tail end. All of the trestles are interchangeable, except the one which carries the tail table and those making up the head rigging. At the rear end of the machine are two braces which may be attached to the next trestle forward or which may be swung around and placed against the ground to support the machine. The trestles are braced by means of diagonal braces against the girders, thus stiffening the machine. Hangers are attached to the girders and carry the upper track, which is made of flat pieces of steel about 6 in. wide and 3/8 in. thick. These are usually in 8-ft. lengths. The girders are a little short of 16 ft. in length, the distance from center to center of trestles being 16 ft.

The carriages or travelers which carry the buckets are provided with wheels hung upon the upper track. Each traveler contains a large wheel over which the bucket rope passes. These tub ropes, shown in Fig. 22, are attached to an equalizer carried by a small traveler near the forward end of the machine. The ropes are of the exact length required for spacing the travelers 8 ft. apart. The main hoisting rope, carried on the drum nearest the boiler, is attached to the equalizer and runs through a large block at the forward end of the head rigging. By means of this main hoisting rope the buckets are raised or lowered into the locks in the travelers. Another rope runs from the outer drum of the engine through a smaller head block in the head rigging and over the trestle to the tail table at the rear end of the machine. The rope passes through this table, which contains two blocks, one at the top and one at the bottom, and back through the table to the rear end of the last traveler. By means of this rope the buckets are drawn to the rear of the machine as the hoisting rope is allowed to run off its drum.

The traveler is provided with two jaws upon which the tubs rest, thus preventing them from falling into the trench when the main hoisting rope is released. When it is desired to lower the tubs, the locks are raised by means of a latch-lever and rod, after which the main hoist rope is very slowly released, constant tension being kept upon it, until the lugs on the tub ropes have passed through the locks. The jaws of the locks may then be allowed to drop, the rope passing between them. The tubs are then gradually and carefully lowered into the trench, the engineer keeping a constant strain upon the hoisting rope so that he may stop them at any moment upon signal from the latchman, who stands on a running board near the forward end of the machine with one hand on the bell cord and the other free to operate the latch-lever.

When the empty tubs reach the bottom of the trench, the ropes attached to them are unhooked and hooked onto another set of full tubs. The signal is then given by the latchman to the engineer to hoist the tubs carefully into the locks. The lugs on the tub ropes are conical in shape, and when raised ultimately lift the jaws of the locks and pass through them to a height sufficient to allow them to drop. When the locks have thus dropped, the latchman signals the engineer, who carefully releases the main hoist rope allowing the tubs to settle back on to the jaws, after which they cannot drop. When the full buckets have thus been landed in the locks, and the latchman is sure that the jaws of all the locks have properly fallen and the tubs are securely fastened, he gives a signal to the engineer who releases the main hoist rope and draws in the tail rope, thus drawing the buckets to the rear of the machine. They are dumped by the dumpman at whatever point is desired, either into the trench, on the bank, or into carts provided to carry the surplus material to the spoil bank.

When excavation in a section has been completed, a rope, one end of which is secured to the engine bed, is carried through a snatch block secured to a deadman ahead of the machine, and back to a winch on the engine. The machine may then be drawn ahead by coiling this rope around the winch. Thus only one engine is required for operating the machine and moving it ahead. The sizes and capacities of these machines are given in Table 9. As the tubs are spaced 8 ft. apart, the four-bucket machine will provide for the excavation of a section of trench 32 ft.; the six-bucket machine one of 48 ft., and the eight-bucket machine one 64 ft. long. Machines may be had with double or single upper tracks. The nominal capacity of the double-track machine is 50 per cent. greater than the single trench machine, as one set of buckets is being hoisted while the other is being lowered. Thus three sets of buckets are continually in use, one set being filled, one hoisted and carried to the dump, the other dumped and returned to be loaded.

TABLE 9.—SIZES AND CAPACITIES OF CARSON TRENCH MACHINES

No. of tubs hoisted at a time	No. of tubs furnished with machine	Single or double upper track	Capacity of machine when run at moderate speed continuously for 10 hours, with tubs holding 5.5 cu. ft. each	Length of working section	Horse-power double drum, double cylinder hoisting engine required
4	12	Single	200 cubic yd.	192 feet	20
6	18	Single	300 cubic yd.	288 feet	20
8	24	Single	400 cubic yd.	320 feet	20
4	16	Double	300 cubic yd.	192 feet	20
6	24	Double	450 cubic yd.	288 feet	20
8	32	Double	600 cubic yd.	320 feet	30

The capacities given in Table 9 are nominal capacities. It is not to be expected that these capacities will be reached continuously for long periods of time. As a matter of fact, an average of 100 cu. yd. per day of 8 hours is very good work with a six-bucket, single-track machine, and often the output of the machine will fall considerably below that amount, due to delays from various causes such as time required for placing sheeting, lack of sufficient teams to carry the surplus material away, difficulties due to ground water, changing laborers from one section to another, pipes to be moved, and a multitude of obstacles encountered in this type of work.

Three counter-buffers are provided with each single-track machine. These are spaced 48 ft. apart on a six-bucket machine and near the forward end. A buffer is attached to the rear traveler, so that when the empty tubs which are being drawn in by the hoisting rope reach the counter-buffer, the carriages stop and the hoisting rope then raises the buckets slightly so that the latchman has an opportunity to lift the jaws of the locks. The buckets are then lowered into the trench.

If excavation is carried on in the section nearest the hoisting engine, the counter-buffers for the next two sections are tied so that the carriages can be pulled past them to the forward counter-buffer. In very hard digging, and sometimes in other cases, excavation is carried on in two or three sections simultaneously. In this case the latchman is required to operate the counter-buffers from time to time as may be necessary. If the buckets are to be lowered in the section farthest from the engine, the buffer of the last carriage will engage the counter-buffer farthest from the engine, the tubs will be lifted, the locks opened and then the tubs lowered. If, on the other hand, work is progressing in the second section, the last counter-buffer from the engine must be lifted to allow the buckets to pass forward to the middle counter-buffer, which engages the buffer on the last carriage, after which the tubs can be lowered into this section.

Each tub is provided with a pair of common bails and a latch. When the latch is lifted one of the bails is released, allowing the bucket to be revolved. The latchman releases these latches one at a time, as the tubs pass him, dumping the tub and turning it back into position and latching it, or sometimes he will release the latches and dump the tubs as they pass him going out and right and latch them as they are drawn past him on the return trip.

A sufficient number of trestles must be provided to allow for hoisting in as many sections as it is desired to devote to excavation, usually at least two; to provide space for the masonry construction, which would usually require two sections; and to provide suitable additional space for backfilling the trench, which should generally be two sections, making a total of six sections back of the engine. In the case of a six-bucket machine each of these sections would be 48 ft. long, making the total length of the working section 288 ft. The method of operating a machine and of carrying on the work in the trench is well illustrated by Fig. 23, in which excavation is represented as being carried on only in the head section, the brick sewer is being laid in the next section, the completed sewer is being allowed to stand until the cement has an opportunity to set, in the next succeeding section; while the remainder of the sections are being used for backfilling the trench. This is a double-track, four-bucket machine, using three sets of buckets. One is being filled, one is being lowered into the trench, and the third is being dumped.

The manufacturers of this machine claim for its advantages that the earth is handled but once; all operations are carried on over the sewer, thus neither obstructing the street nor trench operation; a compactness of work is secured, by which it is carried on systematically; there is a systematic division of labor so that the work of each laborer or pair of laborers can be observed and efficiency thus obtained, and excavation in quicksand and soft mud can be done more successfully than with hand work, or the use of apparatus requiring very large tubs and slow operation.

The force required to operate one of these machines consists of an engineer, fireman, latchman and tubman. In some cases where the work is proceeding slowly, the engineer can do his own firing. It is sometimes thought desirable to use boys for latching and dumping as they are quicker and lighter, whereas the older men are slower and do not get along as well on the running boards, which are usually 2 or 3-in. plank 12 in. wide and about 18 ft. long, extending from trestle to trestle the entire length of the machine. It is very essential to have a careful and alert man or boy to do the latching, as he must observe carefully each of the travelers to make sure that the jaws have fallen before the engineer releases the main hoisting rope, otherwise a tub may fall through one of the locks, in which case, unless the engineer is remarkably skilful, it is likely to fall to the bottom of the trench, to the great danger of laborers below. Even where the engineer is quick enough to stop the tub, the strain upon the tub rope may be great enough to part the rope, in which case the bucket will fall to the bottom. The latchman should be fairly well acquainted with the machine, and each noon should look over the travelers and the upper track and see that all bolts are tight and that the travelers and sheaves are well oiled. The authors have also found it desirable to have a skilled mechanic, or perhaps the engineer, go over the machine carefully on Sundays, to make sure that the ropes are properly adjusted, that all parts of the machine which have worn are replaced by new ones, and that the whole mechanism is in perfect condition. Too much emphasis cannot be laid upon the necessity of having the machine in good order, as it is a source of danger to men working below it if it is not in condition for successful and safe operation.

For ordinary sewer construction the six-bucket single-track machine is probably the most convenient and desirable type. If the trench is very wide, or the excavation exceedingly hard, it may be desirable to use the double-track machine, thus increasing the output. Where the machine is to be taken around curves it is desirable to use the narrow track rather than the I-beam track which is sometimes furnished. Machines of this kind can be taken around curves of fairly short radius, but difficulties are encountered when this radius is less than 100 ft. A skilful foreman, who has had experience with these machines, however, will successfully take them around a curve of very short radius,

Moving forward requires usually but about 10 minutes shut-down of the machine. The lower track should be laid before the excavation of the section being worked is finished. When the track is laid, the deadmen provided and the moving ropes are in place and attached to the winch, excavation in the bottom of the trench is stopped and the machine is quickly drawn forward. Immediately after the machine has reached its new position, the work can be resumed.

The cost of operation depends primarily upon the cost of labor, fuel and rental. The union wage for engineers around Boston is $25 for a 44-hour week with time and one-half for overtime and 65 cents per hour for broken time. Firemen are usually paid the same rate as common laborers.

The charge for a six-bucket, single-track machine including suitable engine, is about $200 per month, the cost of unloading from cars, hauling to the work and erecting depending upon the skill of the men employed and the distance it is hauled. When the men upon the work have used such machines many times, as in the case of some municipal day-labor organizations, a machine can be taken out and erected ready for operation in two days, and can be taken down and packed up at headquarters in from one day to one and one-half days. The cost of taking out and setting up where the distance from the shop yard or railroad is not more than 2 miles, should average about $100, and the cost of taking down and loading for re-shipping or packing away in the storehouse should be about $50. Where the men on the work are not familiar with the machine and handling it, these costs may be doubled or trebled.

The amount of coal used by a six-tub, single machine, upon nine jobs in Worcester, Mass., averaged 561 lb. per day, the minimum being 501 and the maximum 646 lb. These pieces of work each lasted for several months, and were not exceptional for work in this part of the country. On one piece of work where a four-tub, single-track machine was used, 473 lb. of coal were used per day. To arrive at the real cost of the use of the machine the cost of setting up and taking down and transportation between shop or cars and the job must be added. If the job is of long duration these items will make only a small addition to the daily cost of operation. The cost of moving ahead, equivalent to the cost of one additional man per day, must be included in the estimate. There must also be a slight addition for minor repairs, inspection, oil and waste, so that the net cost of operation ought not to be figured, in estimating work, at less than $25 per day. Based upon this estimate and an average of 100 cu. yd. per day excavated, the cost per cubic yard would be $0.25. This cost includes only the cost of hoisting the excavated material, carrying it back and dumping it into the trench or into carts to be hauled away. The cost of picking and shovelling in the bottom of the trench and of tamping the backfill or hauling waste material to the dump must be added to this, to arrive at the true cost of excavation, exclusive of such items as sheeting, pumping, etc.

Potter Trench Machine.—Another excavating apparatus especially designed for trench work is the Potter trench machine, Fig. 24. This is a cable-operated, bucket machine, running upon a track laid on the ground like the Carson trench machine. A standard machine is 10 ft. 6 in. wide and the height of the trestles above the ground is about 7 ft. On top of the trestles are two rails on which a car is moved backward and forward. On this car are carried the tubs, usually two in number, although the car can be equipped for four, or one of them may be taken off and the machine operated with the remaining one. This machine is operated by a double-drum hoisting engine carried on a car at the forward end of the machine. The machine is moved ahead from section to section like the Carson trench machine. Twelve buckets are usually supplied with each machine. They are made of steel and vary in capacity as desired from 1/4 to 1 cu. yd. For very wide trenches, these

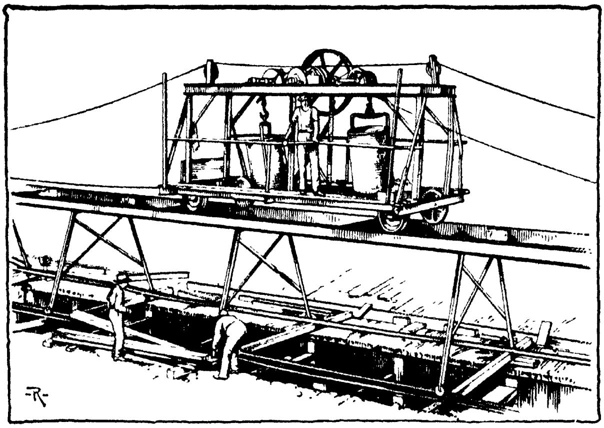


FIG. 24—Potter standard hoister and conveyor.

machines may be had wide enough to accommodate two upper tracks and two cars, thus greatly increasing the output of the machine.

Potter Excavator and Conveyor.—The Potter Manufacturing Co. also makes a machine known as the Potter Excavator and Conveyor, Fig. 25. This is equipped with an orange-peel or clam-shell bucket by means of which digging, as well as hoisting and conveying, is done. The material thus excavated is raised and dumped onto a conveying car which runs on the upper track. When the car is loaded it is pulled to the rear of the machine, under a scraper, which scrapes the material off and allows it to fall into the trench as backfilling.

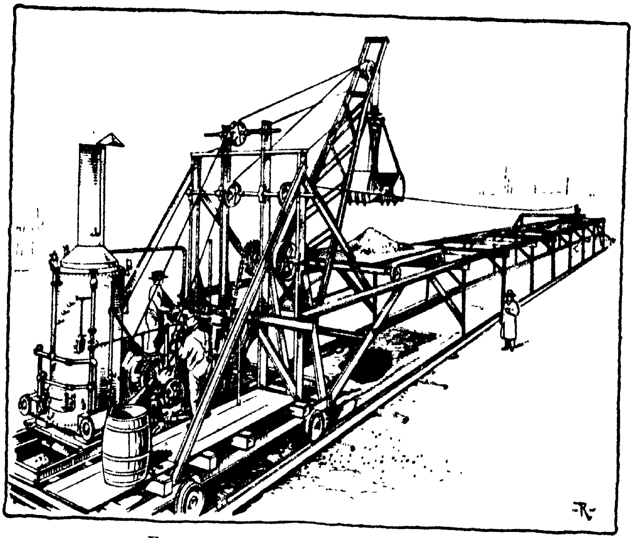


FIG. 25.—Potter excavator and conveyor.

The Cableway.—The cableway, which is used so frequently on many classes of work, is occasionally employed on sewer trench excavation, and some special cableways have been made for this purpose. A large cableway of the ordinary type is not particularly well adpated for sewer trenching. For this work, light towers which can be easily moved should be provided, and the cableway should be relatively short, usually not over 300 ft. in length. Only one tub is handled at a time, and this has a capacity varying according to the requirements of the work, from 1/2 to 1-1/2 cu. yd.

As a cableway is relatively high above the ground and is supported

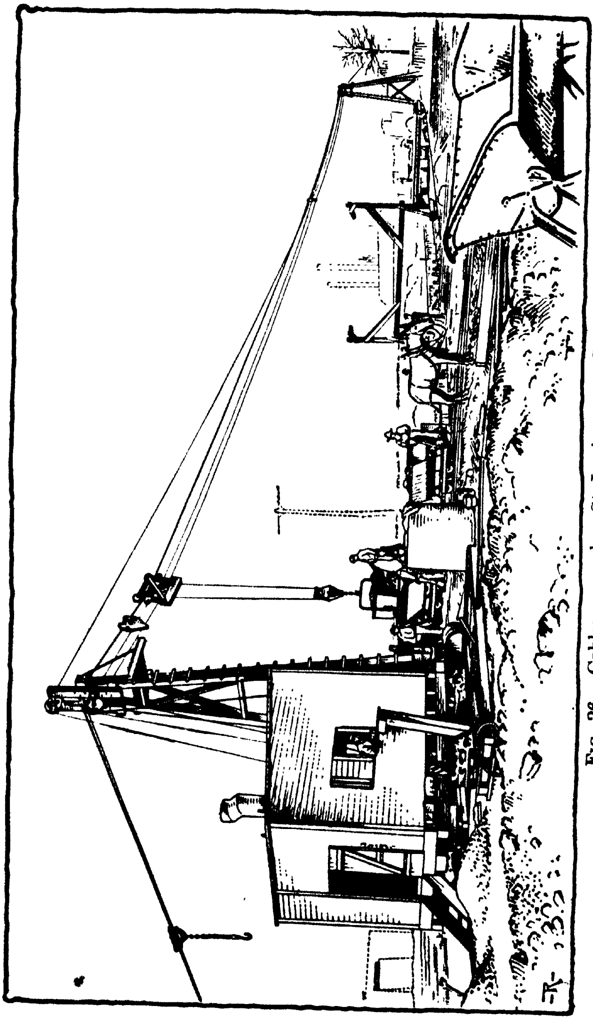


FIG. 26.—Cableway used on St. Louis sewers (Lambert).

FIG. 27.—Steam shovel taking 10-foot first cut in sewer trench.

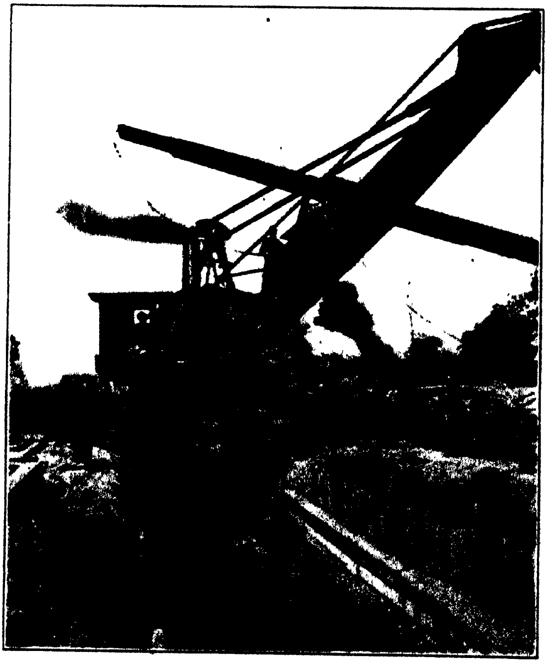


FIG. 28.—Steam shovel with high crane and long arm.

Attention is called to the omission of braces for the upper rangers, which was made possible by using steel beams as false rangers as temporary supports for the sheeting, also to the omission of the second and third rangers for some distance.

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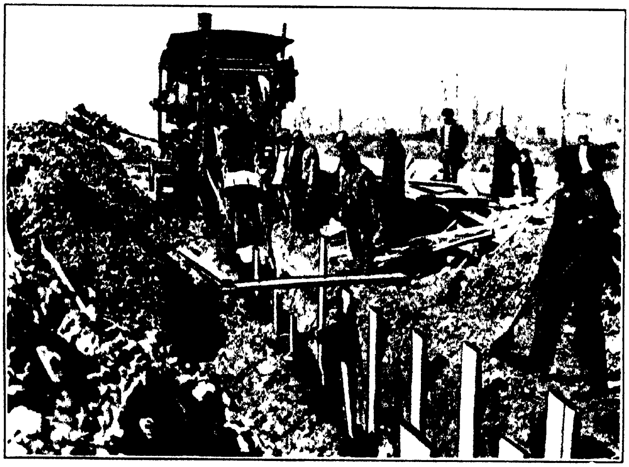


FIG. 29.—Austin trencher excavating a trench 36 inches wide and 15 feet deep.

and steadied only at the ends, 300 to 1000 ft. apart, it is difficult to prevent the buckets from swinging and hitting and occasionally knocking out the timbering and endangering the men in the trench. It is also difficult to land the buckets gently and if landed roughly there is danger to the men and difficulty in moving the empty bucket to the desired position. Similar, though less serious, trouble attends the hoisting. Another objection to the cableway upon sewer work is due to the fact that it cannot be moved forward quickly but must be taken down, carried forward and again erected every time it is moved. This operation consumes considerable time during which all excavation is stopped.

On the other hand, the cableway possesses some advantages over some of the other trench machines, as the cable is high above the street and there is no track to maintain and keep clear. The excavated material may be piled as high as desired under the cableway. There is also less danger of damaging the machine when blasting. As the cableway is supported only at each end it adds no weight to that of the banks to be supported by the sheeting and bracing.

The standard 400-ft. span sewer cableway made by the Lambert Hoisting Engine Co. is shown in Fig. 26, a view taken on some sewer work in St. Louis, where such cableways have been used to a considerable extent. A double-drum hoisting engine is used on these plants, built to enable the operator to hoist and convey his load simultaneously.

Carson-Trainor Hoister and Conveyor.—For trenches in which the cableway type of machine is desirable but its system of anchorage is objectionable, a type of machine has been devised, by which single buckets are operated much the same as by the cableway, but are carried upon a steel track supported by wooden or steel frames of similar design to those of the Carson Trench Machine. This is known as the Carson-Trainor Hoister and Conveyor and is moved forward in the same manner as the trench machine.

Steam Shovels.—While the steam shovel is not particularly well adapted to ordinary sewer construction, it has been used with more or less success upon some large work. For this purpose it is usually desirable to provide an unusually high crane or a long dipper arm or both, although a shovel of standard dimensions may be used for a first cut in a trench, ultimately to be carried deeper, or for the whole excavation in a very shallow trench. The use of such a shovel for making the first cut on the Southern outfall in Louisville, Ky., 1908, is illustrated in Fig. 27. This shovel was moved upon rails laid at the bottom of the cut. It was of standard design and made a cut about 10 ft. deep, the excavated material being discharged into cars run on a standard gage track close to the edge of the trench.

A shovel designed for sewer construction is shown in Fig. 28. This is carried by a specially constructed car, moving on rolls running on planks on either side of the trench. The crane is high and the dipper arm is long, so that it was possible to excavate to a considerable depth. Similar shovels are sometimes mounted upon traction wheels which run upon heavy timbers on each side of the trench. About 10 lin. ft. of trench may be excavated for each move of the shovel, each section being thoroughly braced before the shovel is moved ahead, to prevent the caving of the banks while carrying the shovel.

The capacity of steam shovels varies greatly and the capacity of a shovel used upon a sewer trench is likely to vary greatly from day to day. While the nominal capacity of a shovel may be perhaps 1000 or 1500 cu. yd. per day, the delays incident to the work are often so great that only a relatively small percentage of the nominal capacity is excavated. Such delays may be due to the sheeting and bracing of the trench, the placing of masonry and waiting for masonry to set and become strong enough to carry the backfilling. If the shovel is used only to excavate the upper part of the trench, it is probable that the excavation of the lower part will not proceed as rapidly as the shovel is capable of removing the upper portion. The steam shovel will therefore remain idle for considerable periods of time, thus greatly reducing the nominal output.

In estimating the cost of steam shovel work on sewers these elements of delay should be given proper weight. While the cost of steam shovel excavation under most favorable conditions, where trenches are relatively shallow and delays are few, such as ditching for drainage purposes where masonry structures are not required, may be as low as 5 to 10 cents per cubic yard, the cost of ordinary sewer excavation, where trenches are fairly deep and the usual difficulties are encountered, is likely to run from 15 to 25 cents per cubic yard, even upon relatively large work. These estimates do not include the cost of pumping, sheeting, handling backfill, transporting surplus material to the spoil banks, etc.

It is difficult to sheet and brace securely a trench excavated by steam shovel, as the bracing, if put in before the excavation is carried dangerously deep, will be in the way of the dipper. Furthermore it is not possible to excavate to the exact lines required for the sheeting. Either the shovel excavation must be kept narrow, necessitating much hand trimming of the banks, or it will be too wide in places, making it impossible to sheet and brace the banks properly. Where the trench is through paved streets, or streets in which gas and water pipes are laid and where buildings stand near, damage is almost sure to follow the use of a steam shovel because of settlement of the adjoining ground due to improper sheeting and bracing. In some cases, also, it has been found that the great weight of the shovel, necessarily supported close to the trench, has increased the strain upon the timbering and caused the settlement of the adjoining ground.

In spite of these facts, the steam shovel may be used successfully in some cases, for making the first cut for deep sewers of large dimensions, the material so excavated being hauled away and wasted, while the remaining and deeper portion of the excavation is made by one of the other methods herein outlined, the material excavated thereby being retained for backfilling the trench; and it may prove advantageous upon some other trench work where conditions are particularly favorable.

Endless Chain Machines.—Machines of the endless chain variety are usually operated directly on the ground by engines mounted upon wheels.

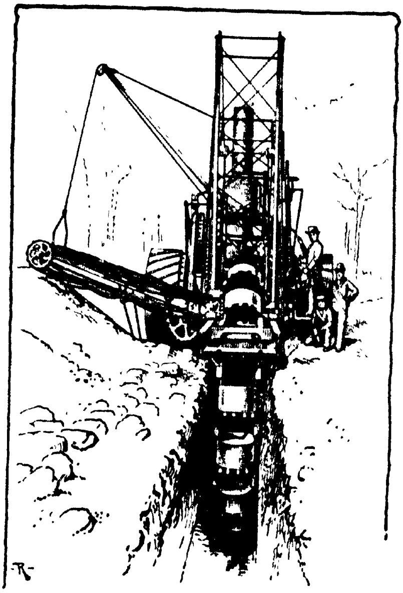


FIG. 30.—Buckeye traction ditcher.

The digging is done by buckets carried by an endless chain running over sprocket wheels on the end of an arm suspended from the rear of the machine and adjusted to permit the excavation of the trench to a precise grade regardless of the inequalities of the surface over which it passes. The width of the trench excavated is governed by the width of the buckets selected, each machine being supplied with buckets of several widths. The material excavated by the buckets may be dropped upon an endless belt operating crossways of the ditch and discharging the excavated material in a windrow on either side of the trench or into wagons to be hauled to the rear of the work for backfilling or wasted.

There are a number of different makes of machines of this type, each having its particular method of loosening and excavating the material, all of which should be investigated before the most desirable machine can be selected for the particular work in hand. The Austin Trencher is illustrated by Fig. 29. The advantage of these machines over those of the Carson type is that no picking and shovelling is required, the machines doing the excavating as well as the hoisting, and discharging onto a spoil bank at the side of the trench or into carts. These machines are adapted for relatively shallow trenches through virgin soil where bracing is not necessary, and where pipes, conduits and sewers crossing the trench are not encountered. In some classes of material which require bracing, it may be possible to excavate a short distance ahead of the bracing, moving the machine along and then adjusting the braces behind it, as illustrated by Fig. 29. This would not be practicable in many sandy soils, and especially where there is considerable ground water likely to cause caving of the banks. The sizes and capacities of Austin trenching machines are given in Table 10A, and those of the Parsons machines in Table 10B.

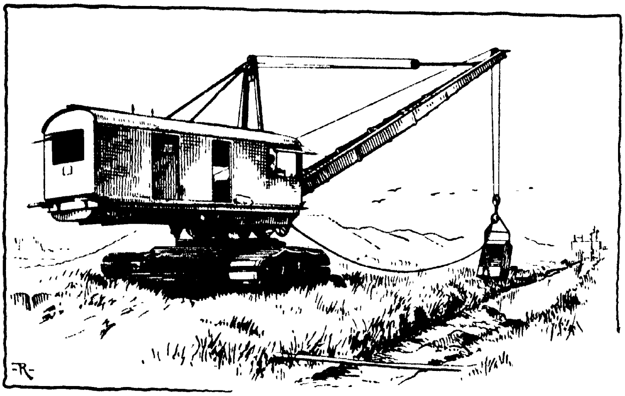


FIG. 31 —Excavating a ditch with a drag-line scraper.

Another somewhat similar type of trench excavator has the buckets attached to a large wheel instead of endless chains. The Buckeye Traction Ditcher, Fig. 30, is an example; it has been used mainly in laying drain tile, but has also been employed in sewer and water-main trenches of relatively narrow width. The trench shown in the illustration was

TABLE 10A.—SIZES AND CAPACITIES OF AUSTIN TRENCHING MACHINES

Type	Power	Weight, tons	Excavation		Nominal speed per min	Traction bearing		Overall dimensions		Wheel base, ft.
			Max depth, ft	Widths[1] inches		Dimensions each bearing	Total area both bearings sq ft	Width, ft	Length, ft.	
000	Gasoline	9	6	12, 15, 18	1 ft - 10 ft	24 in × 60 in	20	7½	33½	12½
00	Gasoline or steam	11½	8	15, 18, 24	1 ft -10 ft	30 in × 60 in.	25	8	36	13
0	Gasoline	20	10	18, 24, 30, 36	1 ft –10 ft	30 in × 72 in.	30	10	45	16
1	Steam	24	9 to 15	24 to 39[3]	1 ft - 6 ft	30 in × 108 in	45	10	44	16
10	Steam	33	15[2]	24 to 72	3 in - 36 in	28½ in × 132 in	52¼	10½	57	21½

TABLE 10B.—SIZES AND CAPACITIES OF PARSONS TRENCH EXCAVATORS

Type	Power	Weight, tons	Excavation		Buckets			Wheels, no	Caterpillar traction[4]	Width, ft	Length, ft.
			Depth, ft	Width, in	Length, in	Width, in	Depth, in				
KO	Gasoline or steam	11	8	22	24	22	9	2	Used	9½	42
K	Gasoline or steam	14	12	22 to 42	24	22	9	2	Used	9½	46
E	Steam	24	20	28 to 60		28		6	Optional	10	35
F	Steam	26	20	28 to 78		28		6	Optional	10	35

TABLE 10C.—SIZES AND CAPACITIES OF BUCKEYE TRACTION DITCHERS

Type	Power	Weight, tons	Excavation		Wheel base, ft	Front wheel tread, ft	Width rear tires, ft	Cost with	
			Depth, ft	Width, in				Round wheels	Apron wheels
5	Gasoline	15	6	20-24-28	14½	8½	8	$4,200	$4,700
6	Gasoline or steam	16	7	20-24-28	14½	7½	8	4,500	5,000
7	Gasoline or steam	17½	7½	20-24-28	17½	7½	8½	4,700	5,200
8	Gasoline or steam	21	7½	24-28-32-36	14½	8½	9½	5,500	6,000
9	Gasoline or steam	33	10	28-36-42	20	8½	10½	7,300	7,900
10	Gasoline	36	12½	28-36-42	24	8½	10½	8,000	8,750

[1] These widths may be varied by change in side cutters.

[2] Boom may be extended for 20 ft. depth for widths up to 36 in. only.

[3] By 1-in. increments.

[4] The caterpillar traction has a tread of 26 in. and a length of 105 in., giving 26-1/2 sq. ft. of bearing surface for both sides.

32 in. wide and 12 ft. deep, on a contract taken by Laurin & Leitch, Montreal, P. Q.

Drag Scrapers.—Drag scrapers have long been used to remove the upper portion of the trench, but have usually been operated by animal power. More recently similar devices have been operated by portable derricks built with extremely long booms which handle a specially designed scraper. This scraper is dropped from the end of the boom into the trench and drawn along the bottom until it is filled, when it is raised by the cable, moved to one side by the boom, and its contents deposited along the trench or in wagons or cars to be hauled away for backfilling or to be wasted, as may be desired.

The machine shown in Fig. 31 was an electrically operated Bucyrus excavator, but the steam-operated machines are similar in appearance. The boom was 45 ft. long and the bucket held 1-1/4 cu. yd. The machine moved on caterpillars instead of ordinary wheels, and was employed on an irrigation ditch by the U. S. Reclamation Service.

Derricks and Cranes.—Derricks and cranes are frequently used for sewer construction, and may be supported either upon rolling platforms or wheel trucks moving on the ground or on tracks. These derricks are usually placed along the side of the trench and are used to operate orange peel buckets, or to lift buckets which have been filled by laborers in the ditch, dumping the material in windrows along the trench, or into wagons or cars for hauling back to the finished portion of the sewer for backfilling or wasting.

For this type of machine the regular locomotive crane pivoted to operate in any direction is most convenient, especially as it may be moved quickly forward or backward along its track by its own power. With proper management this machine should seldom be idle, for when it is not needed in excavating it can be used in loading or unloading cars or wagons, in placing materials in the trench, in operating scrapers for backfilling, or in pulling sheeting.

The locomotive crane, however, is an expensive machine, costing about $7500. On this account, many contracts are too small to warrant its use. A wooden stiff legged derrick operated by an ordinary double-drum hoisting engine, costing from $1500 to $2500, has been found very useful upon large work. A derrick of this sort used on the Louisville sewers is shown in Fig. 32. The length of boom will depend upon the width of trench and the available space for the spoil bank, but will generally not exceed 30 ft.

Excavating Buckets.—Upon some classes of large sewer work where the material to be excavated is of a loamy or sandy nature, the use of orange peel or clam shell buckets operated by locomotive cranes or stiff legged derricks may prove economical. Obviously it is not possible to trim banks accurately to line with such excavators. This must be done by hand, the material trimmed off being thrown toward the center of the trench where it can be picked up by the bucket. Where such buckets are to be used it is desirable to make the sections between braces 10 ft. or so long, to allow ample room for the swinging of the bucket, which cannot be altogether prevented. With such apparatus, as with the steam shovel and other mechanical excavators, it is not desirable to carry the excavation to within 6 to 12 in. of subgrade. This latter portion of the excavation should be done by hand, because digging with buckets or dippers in the immediate vicinity of subgrade is likely to loosen the material, thus giving an opportunity for the settlement of the masonry structure to be placed upon it. Furthermore it is not possible to excavate with such machinery exactly to a given elevation. If the attempt is made to excavate exactly to subgrade, the probablility is that much of the excavation will be carried slightly below subgrade. Refilling with some suitable material will then become necessary. Fig. 32 shows an orange peel bucket dumping its contents. In excavating it is dropped in an open position to the bottom of the trench and then closed by hauling on the main rope. The heavy leaves or scoops are so formed and the weight of the bucket is so great that they dig into the material in the trench as they close.

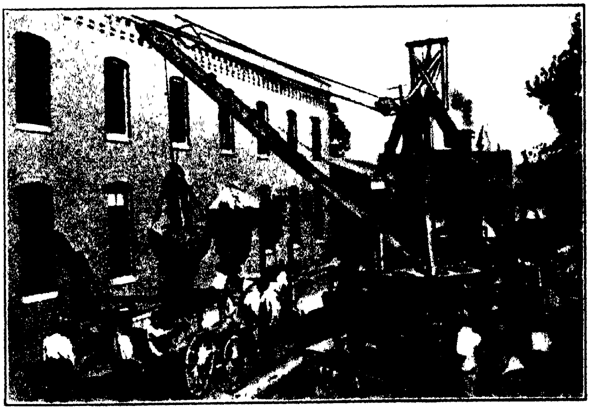


Fig. 32.—Traveling derrick, Louisville.

Economical Use of Machinery.—The type of machine to be used and the extent to which it is used will vary according to the conditions surrounding each particular undertaking. Where much rock excavation is anticipated, the necessary delay in its excavation may preclude the use of expensive machinery upon the excavation of the overlyin earth as it will be likely to remain idle much of the time.

Success in the use of machinery for excavation is dependent upon continuity of operation, at a rate approximating its nominal capacity When machinery is employed on sewer construction a full quota o labor, teams, cars, etc., should be provided, so that the machinery may be constantly employed, and consequently the unit cost of the machinery charge may be reduced to the lowest possible figure. In this connection it is important to note that the machinery should be kept constantly in repair, the repairs being made at times when the work is shut down for any cause.

CHAPTER V

METHODS OF ROCK EXCAVATION

The method to be adopted for the excavation of rock in sewer trenches depends upon the quality and quantity of rock to be excavated. Ledge varies greatly in character, from that which is disintegrated and soft and may be removed by picking and shoveling as readily as some kinds of earth, such as hardpan, to extremely hard, igneous rock like granite and trap, which require drilling and blasting for removal. Between these two limits there are many kinds of rock of varying degrees of hardness. Some may be removed by picking, barring and wedging without the use of explosives, and some, like limestone, may lie in nearly horizontal strata and may be removed by methods similar to those employed in the ordinary quarrying of building stone.

The method to be adopted for excavating a certain quality of rock may vary under different conditions. In some cases the quantity to be removed is so small or the danger of damaging adjacent structures may be so great as to warrant its removal by picking, barring and wedging even where the nature and quality of rock are such as to warrant drilling and blasting under other conditions.

The methods commonly used for drilling ledge may be divided into two classes, hand drilling and power drilling. Hand drilling in turn may be subdivided into three classes, single hand, double hand and churn drilling. Power drilling may be classified in accordance with the type of machine drill used, which may be a rotary or core drill, a reciprocating or percussion drill or a hammer drill.

Hand Drilling.—For small holes and occasionally for large ones of moderate depth, the drill may be held in one hand and struck by a hammer held in the other hand, the hammer weighing about 4 lb. This method is largely used in quarrying, where a number of small holes are drilled in a line along which the rock is to be split by driving small wedges into the holes between tapered strips of steel. The wedges and strips of steel are called "slugs and feathers."

For larger and deeper holes it is customary to have one man hold and turn the drill, while two or three men strike the head of the drill in rotation with hammers weighing from 8 to 12 lb. In this method, the drills should be turned about 45 deg. each time in order to insure a nearly round hole.

In churn drilling the hole is drilled by the churning of a steel drill, which is raised by hand and allowed to drop of its own weight, or it may be thrust into the hole, although but little advantage is gained thereby. Each time the drill is raised, it is turned about one-eighth of a revolution so as to prevent its striking the bottom of the hole successively in the same position. By confining the turns to about 45 deg., the hole is maintained more nearly circular than would be the case if a larger turn were given each time. Where added weight is desirable, a ball of iron or steel is sometimes welded to the drill rod, at or slightly below its middle point, care being taken to have the center of gravity of the ball in the line of the axis of the rod.

The bit ordinarily used in double hand drilling is provided with a chisel edge and is made from octagonal steel 7/8 in. in diameter. The wedge-shaped edge varies in sharpness according to the quality of rock to be drilled. It should be made as sharp as possible and yet not break or become rapidly dulled. The angle of the wedge-shaped edge usually varies between 45 deg. for soft rocks and 90 deg. for hard rocks.

Bits are usually made up in sets, depending upon the depth of holes to be drilled. The bottom of the hole must be about 1 in. in diameter to receive the ordinary dynamite cartridge. The finishing drill must therefore have a face at least 1 in. in length, and as a matter of fact, it is usually made somewhat longer, in order to allow for wear. Each bit must be slightly smaller than the bit preceding it in order to allow for wear in drilling. A set of four bits will ordinarily vary approximately between 1-5/8 in. for the starting bit to 1-1/4 in. for the finishing bit. It is necessary to re-sharpen the drills at frequent intervals, not only that they may be reasonably sharp, but that they may be of proper gage.

The cost of hand drilling varies according to the hardness of the rock, although the difficulty of drilling is not always dependent wholly upon hardness. Rock which is seamy and lies at an angle steeper than 45 deg. with the horizontal, may be quite difficult to drill because of the tendency of the drills to bind and stick in the holes. Limestone is usually very easily drilled, while trap rock and quartzite are hard to drill. Some seamy shale, although relatively soft, lies at such a steep angle with the horizontal that it is difficult to drill.

The authors have usually found it desirable to provide one man to turn the drill and two men to do the striking. An illustration of the amount of work done by such a gang of men is furnished by the data given in Columns 1 and 2 of Table 11.

Assuming that the wages paid the laborers for this work were $2 per day of 8 hours, it appears that the cost of labor for actually drilling the holes varied, on the average, from 28 to 60 cents per foot of hole drilled. This, however, does not include the cost of the steel, of sharpening the drills, or of the time of the foreman, supervision, or any cost for supplies, bookkeeping, etc. The holes drilled were of proper size for the ordinary cartridges of blasting dynamite.

TABLE 11.—LENGTH OF HOLES DRILLED BY HAND AND BY STEAM DRILLS IN DAY OF EIGHT HOURS IN SEWER TRENCHES AT WORCESTER, MASS. (1905–1906)

Holes drilled by hand by 3 men		Holes drilled by one 3½ in. steam drill		Character of ledge
Maximum	Average	Maximum	Average	
(1)	(2)	(3)	(4)	(5)
24.0 ft.	12.3 ft.	68.0 ft.	50.3 ft.	Soft, seamy, mica schist on edge
20.7	13.2	76.0	49.5	Soft, seamy, mica schist on edge
21.2	17.8	42.0	30.3	Gneiss, hard with seams
13.0	10.2	78.0	43.2	Schist, very soft in some places
19.5	11.9	38.0	32.1	Traprock, very hard
28.6	21.5	64.0	45.6	Very soft mica schist

Note.—The holes drilled were from 2 to 4 ft. in depth, averaging 3 ft. Steam drills accomplished from two to four times as much work as the hand drills.

H. P. Gillette, in his work entitled "Rock Excavation," gives an approximate esimate of the rate of progress of double hand drilling, two men striking, when drilling a 6-ft. vertical hole, as 7 ft. in 10 hours in granite, 11 ft. in trap and 16 ft. in limestone.

Spacing of Drill Holes.—The spacing of drill holes and the quantity of rock loosened per foot of hole and per pound of dynamite vary greatly with the character of rock to be excavated, the strength of the dynamite used, the width of trench and the necessity of loading lightly to protect buildings and underground structures. Blasting in trenches requires much more powder than blasting on the surface, for it is possible to provide but one face, and that often a narrow one, toward which to blow. Prof. Henry N. Ogden, in his book on "Sewer Construction," p. 225, has covered this subject very clearly.

"The spacing and depth of the holes, as well as the amount of the charge, will depend on the methods employed and on the specifications followed. The behavior of different kinds of rocks is most confusing to the foreman who meets a new formation. In soft rock and in sedimentary rock in thin layers, properly distributed blast holes will carry down a trench with regular and smooth sides, but granite and igneous rocks are broken out in irregular and uncertain lines, often loosening the dirt cover for many feet on each side of the trench, if not actually filling the trench with such dirt. Most specifications require excavation in rock to be carried to a depth 6 in. below the bottom of the pipe. In sedimentary rock in thin layers, or when a thick layer comes just above the excavation bottom, it is only necessary to drill the blast holes to the bottom of the desired trench. But in tough granites and thick, hard limestones with strata disadvantageously placed, it is frequently necessary to drill 1 ft. below the trench bottom in order to have every point of the bottom at least 6 in. below the pipe.

"The usual practice of placing the holes in a trench is to space them about

3 ft. apart longitudinally and transversely about the same distance. Thus, in a trench 3 ft. wide, two holes are drilled, one on each side of the trench. In a trench 6 ft. to 8 ft. wide, three holes would be used, one on each side and one in the middle. In a trench 14 ft. wide, in Newark, N. J., five holes in each row were used, the distance apart, longitudinally, of the rows being 4 ft. In soft limestone the author has, for trenches for 6-in. pipe not over 8 ft. deep, particularly when only the bottom of the trench was in rock, put down a single row of holes in the middle of the trench, but a large amount of picking and hammering is always necessary to finish up the work.

"As to the depth of the hole, the necessity of avoiding accidents, excessive noise, and rattling in nearby houses, limits the amount of the charge. Usually the depth of the holes is made the same as the distance between the holes, although in tough rock the depth can with advantage be made greater than that distance. The deeper the holes, the cheaper the work, since frequent changing of drilling machines means loss of time. Gillette gives the following theoretical table (Table 12) to show the effect of spacing of holes upon the cost of excavation, tabulating the number of feet of hole drilled per cubic yard excavated:

TABLE 12.—EFFECT OF SPACING OF HOLES ON COST OF EXCAVATION

Distance apart of holes, ft	1	2	3	4	5	6	8	10
Cubic yards per foot of hole ...	.04	.15	.33	.59	.93	1.33	2.37	3.70
Feet of hole per cubic yard. ..	27.	6 8	3.0	1.7	1.08	.75	.42	.27

"Since drilling costs from 10 cents to 50 cents per linear foot, an unwise or unforseen combination of high cost drilling with shallow holes near together, may very easily add from $1 to $3 to the cost of a cubic yard of rock excavation. In loose seamy shale, shallow holes near together are necessary to retain the force of the explosion."

Where a trench is to be excavated in a stratified rock like limestone, in which the strata are practically horizontal, it is well to bear in mind the probable necessity of removing practically the whole of the bottom stratum although the grade line may come only a few inches below its upper surface.

From data given in Gillette's "Rock Excavation—Methods and Cost," Table 13 has been compiled, and by reference to this table it will be possible to obtain a very rough idea of current practice in trench excavation regarding the spacing of holes, the quantity of rock loosened per foot of holes drilled, and the quantity of dynamite required per cubic yard of rock. One of the authors found in the excavation of rock in three trenches, the quantities excavated varying from 110 to 2335 cu. yd., that the quantity of dynamite required ranged from 1.4 to 1.82 and averaged 1.58 lb. per cu. yd. of rock removed. He also found that excavation in a very hard rock in trench required about 2 lb. whereas excavation of this same quality of rock in a tunnel required 8.4 lb. of dynamite per cubic yard of rock removed. It should be stated, however, that this tunnel was very small, was so situated that it was not possible to use deep holes and that it was necessary to load very lightly.

TABLE 13.—DATA RELATING TO DRILLING AND BLASTING OF ROCK IN TRENCHES (Gillette)

Kind of rock	Width of trench, feet	No. of holes	Spacing of rows of holes, feet	Length of drill hole per cu. yd., ft	Dynamite per cu yd., lb.
Granite	2½–3	2	3	6	....
Trap	6	3	3	4½	2.6
Trap	8[1]	3	4	2.53	....
Soft sandstone	14[2]	5	4	2.4	1
Sandstone[3]	6	3	3	4½	0.55

[1] 12 ft. deep [2] 10 ft. deep. [3] Seamy rock and holes 4 to 6 ft. deep.

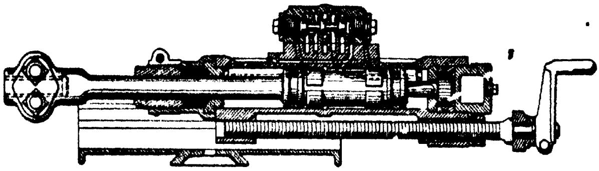
Cleaning Holes.—During the process of drilling water is poured into the holes, which tends to hold the rock powder in suspension and forms a sludge which must be removed from time to time. This may be done by the use of a scraper or "spoon," made by attaching a semi-cylindrical strip of steel to the end of an iron rod about 3/8 or 1/2 in. in diameter. The bottom of the cylindrical portion of the spoon should be turned up much the same as the point of an ordinary tablespoon. Where such a spoon is not available, the broomed end of a round stick of slightly smaller diameter than the lower portion of the hole may be dropped into the hole and withdrawn, bringing with it a portion of the sludge, which may be removed by striking it over a nearby object.

DRILLING BY MACHINERY

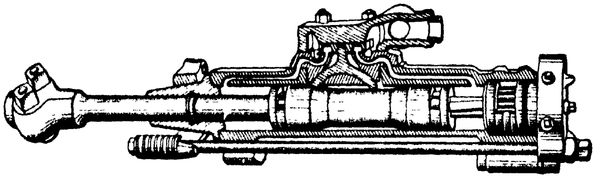
When the depth of holes, hardness of rock or quantity of ledge to be excavated is such that the economical limitations of hand drilling are exceeded, drilling machinery should be used. Of the three different types of drilling machines in common use, the rotary or core drill is rarely if ever used for the drilling required on ordinary sewer work, although it may occasionally be used to advantage for making test borings.

Rotary or Core Drill.—The rotary drill rotates the bit which cuts or chips the rock at its base. The more common form is the so-called "core drill," by which an annular hole is cut by the bit, thus leaving inside the hollow steel a core of the rock which may afterward be broken off and withdrawn, thus furnishing a sample of the material encountered. There are two types of core drills which are described in Chapter I.

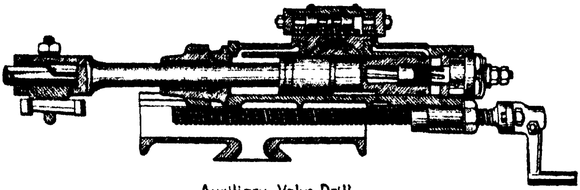
Reciprocating or Percussion Drill.—The reciprocating drill has been used upon all kinds of rock excavation for many years. It is driven by steam or compressed air and is used upon heavy work where hand or hammer drilling would not prove economical. It consists essentially



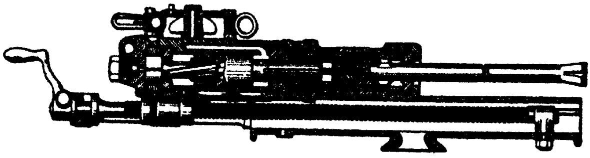
Differential Valve Drill.



Tappet Valve Drill.



Auxiliary Valve Drill.



Butterfly Valve Drill.

Fig. 33.—Four types of valves for percussion drills.

of a steam cylinder in which a piston is driven forward and backward by the steam. The bit is attached to the lower end of the piston rod, which is rotated on the upward stroke in order that the hole may be drilled round and true. The bit is made to follow the rock as fast as it is cut away, by moving the entire cylinder toward the rock by means of a feed screw and crank. This type of drill withdraws the bit from the rock at each upward stroke and forces it back against the rock at each downward stroke, whence its old name of percussion drill.

There are several types of reciprocating drills, differing as to details of construction. The drills ordinarily used are often distinguished by the nature of the valve controlling the steam or air supply, four leading types being shown in Fig. 33.

The differential valve is of the spool pattern, so arranged that the length of stroke and the force of the blow may be governed by the operator. This enables him to employ a short light stroke in starting new holes and drilling seamy rock, whereas after a hole is well started in good ledge a powerful blow may be delivered under full steam or air pressure. This type of valve is desirable on a drill for hard, even rock, requiring a heavy blow and high air pressure.

The tappet valve is of the rocker type which necessitates a full stroke of the piston. This type of valve is used in comparatively soft rocks and with moderately low steam or air pressures.

The auxiliary valve drill is a combination of the differential and tappet types, in which the strain to which the tappet or rocker is subjected is transferred from the main valve to a smaller auxiliary valve. Drills with this valve are used for general work, where the rock may vary from very hard to very soft and the pressure of the steam or air may be variable.

The butterfly valve drill is a later type than the others, and possesses advantages of both the differential and tappet types, in that the valve is positive and instantaneous in action, opens fully at the beginning of the stroke, and has small travel and large port openings.

The size and type of drill to be used depend upon the hardness of the rock and the diameter and depth of holes to be drilled. For ordinary sewer sections where the drills must be used in relatively narrow quarters it is desirable that they be as light as is consistent with the character of work they are to perform. Drills having a cylinder from 2-3/4 to 3-1/4 in. in diameter and a stroke from 6 to 6-1/2 in. in length are commonly used. The feed screw operated by hand varies in length in the different types of machine, but may, for ordinary work, be taken at 24 to 30 in. The difference in length between consecutive bits in a single set should be substantially equivalent to the lengths of the feed screws.

In open trench work, drills are commonly operated by steam, in which case it is important to have the steam supply pipe of suitable size and a boiler of ample capacity. For a 3-1/4-in. drill a steam pipe from 100 to 200 ft. in length should be 1-1/4 in. in diameter. A boiler of at least 10 h.p. should be provided for a drill of this size, but if more than one drill is used, the required horse-power can be obtained by multiplying that required for one drill by the constant given in Table 14, which is a part of a table prepared by the Ingersoll-Rand Co.

TABLE 14.—MULTIPLIERS TO BE USED IN DETERMINING THE BOILER HORSE-POWER FOR ROCK DRILLS FROM THE POWER FOR ONE DRILL

Drills, No.	1	2	3	4	5	6	7	8	9	10
Multiplier	1.0	1.8	2.7	3.4	4.1	4.8	5.[illegible]	6.0	6.5	7.1
Drills, No.	12	15	20	25	30	[illegible]	50	60	70	....
Multiplier	8.1	9.5	11.7	13.7	15.8	21.4	25.5	29.4	33.2	....

The weight of the drill will be approximately 300 lb. and the weight of the tripod on which it is mounted will be approximately 250 lb. without the weights, which will add about 300 lb., making the total weight of the drill mounted upon its tripod, ready for use, approximately 850 lb. The handling of such a drill in a narrow sewer trench is a matter of some difficulty and requires considerable time. It is always necessary to provide at least 2 men to operate and handle the drill, the drill runner and a helper. When the drill must be moved it is usual to call upon a third man. In case two or more drills are being used in close proximity it may be possible to draw the third man from another drill, thus providing only 4 men for the operation of two drills.

Under ordinary conditions the rock pulverized by the drill is carried from the hole by water thrown into it and churned by the up-and-down motion of the bit. In some cases, however, difficulty is experienced in cleaning the hole in this manner, and it is necessary from time to time to remove the bit and pump or "gun" out the hole. To meet this difficulty a drill has been placed upon the market which has a water tube leading through the rotating screw, the piston and piston rod and communicating with the hole in a hollow steel bit. By attaching a water hose to a fitting at the top of the drill, a supply of water can be forced through the machine and bit, thus providing a constant flow of water to the bottom of the hole, from which it rises around the bit, carrying with it the rock dust, and overflows at the surface, thus freeing the hole of sludge. This device is said to be particularly useful for horizontal or up holes required for tunnel work. It is also claimed that compressed air can be forced through this inner tube and drill, thus blowing the rock dust out of the hole in a manner similar to that attending the use of the ordinary hammer drill. This method of ejecting the dust is said to be effective to a depth of about 8 ft.

For excavating rock in tunnel headings, it is usually more convenient to mount the drill upon a mining column or shaft or stoping bar, than upon a tripod. The columns are braced or jacked against the rock in a horizontal, vertical or other position. The drill mounted upon the column may be slid along to the desired position and rotated about the

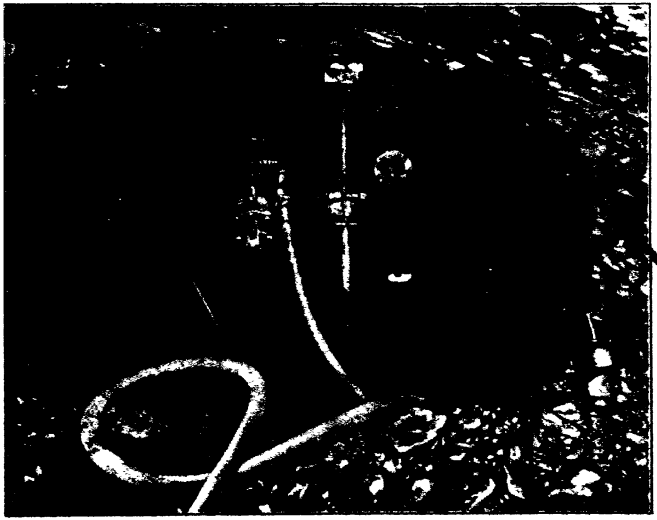


Fig. 34.—Drill on column in rock tunnel for sewer.

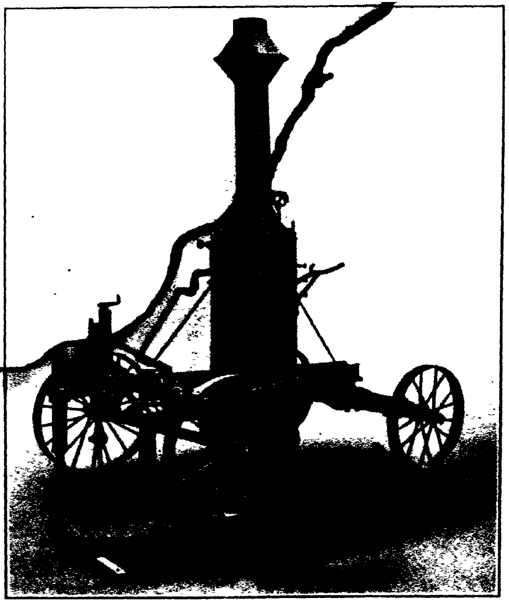


Fig. 35.—Wheeled trench drill (Sullivan)

(Facing page 106)

column in any direction. In Fig. 34 the drill is shown as mounted upon an adjustable arm, onto and from which it can be moved after simply slacking off two nuts. This view was taken in a sewer tunnel in Worcester, Mass.

Upon ordinary sewer work where the number of drills employed is relatively small, it is more common to provide steam than compressed air for operating the drills. It often happens, also, that other machines are operated by the same boiler, so that furnishing power for the drill is only one of the considerations entering into the problem of the selection of the power plant. Compressed air, however, has some advantages over steam, perhaps the most important being its greater elasticity, if the word may be permitted, which causes the air drills to operate in a more snappy and efficient manner than those driven by steam. Another consideration is that the rubber hose connecting the supply main with the drills will last much longer in the case of air, and that there is somewhat less danger of injury to the workmen in case the hose bursts or the connection of the hose with the drill is blown out. Furthermore, the escape of steam from leaking joints, and the exhaust itself, in many cases causes discomfort and hinders the work of the men. There is also considerable loss of power, due to the condensation of steam, especially in cold weather and where long pipe lines are required. Better lubrication is possible when the drills are operated by air as the steam seems to wash the oil out of the cylinder.

TABLE 15.—INFORMATION CONCERNING DRILLS (SULLIVAN) SUITABLE FOR ORDINARY SEWER WORK

Diameter of cylinder, in.	2¾	3⅛	3⅝
Length of stroke, in.	5¾	6⅛	7
Length of feed (depth drilled without changing steel), inches	22	24	24
Depth of hole machine will drill easily, feet	11	18	20
Diameter of hole that may be drilled, in.	1⅜–2	1½–2¼	1⅝–3
Size of drill steel, in.	1–1⅛	1⅛–1⅜	1⅜–1⅛
No. of pieces in set of steel to drill holes to depth above stated	6	9	10
Diameter of steam inlet, in.	¾	1	1
Size of hose to connect to drill, in.	1	1	1¼
Size of steam pipe to carry steam 100 to 200 feet, in.	1	1¼	1½
Size of boiler to supply steam for one drill, h.p.	8	10	12
Weight of drill unmounted, lb.	162	295	325
Standard size of drill shank, in	1×6¼	1⅛×7⅛	1⅜×7¼
Weight of tripod only, lb	215	240	370
Weight of tripod weights, lb.	305	310	400

The use of compressed air for operating drills in tunnels and very deep shafts is almost a necessity, although the authors have driven a short tunnel with steam drills, the exhaust being piped back to the outside air and care being taken to prevent leaky joints. Aside from the fact that less discomfort on account of high temperature is caused where air is used, the exhaust from the drill furnishes ventilation for the headings, which is a very important point. It also makes it possible, by turning on the air from a valve at the shaft, to blow out the tunnel after blasting, thus quickly removing the obnoxious gases.

Information concerning the dimensions, weight and operating conditions of percussion drills of the type suitable for ordinary sewer trenching and tunneling is given in *Table 15.*

Wheeled Trench Drills.—Upon some trench work, notably upon some sewer work in Havana, Cuba, drills and steam boilers have been mounted on the same trucks, Fig. 35, and run over the trench in which the drilling was to be done. When the drill is in the proper position, the rear of the truck is jacked up from the ground so that the jacks may take up the strains and vibration. This machine is intended to save much of the labor required to set up and move a drill mounted on a tripod and to be a machine which can be easily moved about. The drill is mounted upon a bar along which it can be moved a distance of about 3 ft. and about which it can be revolved so that holes may be drilled obliquely as well as vertically. This machine is adapted for trenches from 2 to 5 ft. in width.

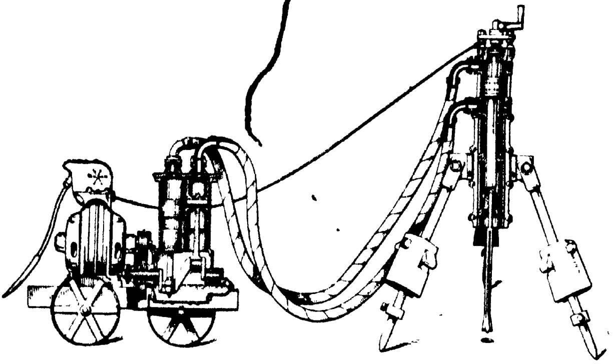


Fig. 36.—Electric-air drill (Ingersoll-Rand)

Electric-air Drill.—The electric-air drill, Fig. 36, is driven by compressed air furnished by a pulsator. This pulsator is geared to an electric motor, using either direct or alternating current, and both are mounted on a small truck for ease in handling. The air is never exhausted in this pulsator, but is simply used over and over again, moving back and forth in a closed circuit. The pulsator requires no intake or discharge valve or water-jackets. This drill may well be used where electric power is available and is cheaper than air or steam power on account of high fuel cost, and where high altitudes impair the efficiency of the ordinary air compressor and where pipe lines would be objectionable. Part of the rock drilling at the Kensico dam of the Catskill water supply for New York was done by these drills.

Hammer Drills.—The hammer drill is a relatively new invention, having come into general use since 1900. With it the bit remains at the bottom of the hole in contact with the rock, instead of reciprocating with the piston at each stroke, as in the case of the reciprocating drill. The piston, or hammer, strikes the upper end of the bit, which is rotated either by turning the drill by hand or automatically by a mechanical device.

The advantages of the hammer drill over the reciprocating drill are that it is light, can be readily handled by one man and requires no tripod or other mounting, as shown in Fig. 37. It is particularly serviceable in narrow trenches where it is difficult to handle the reciprocating tripod drill. Holes may be drilled with this machine in any direction. There is considerable saving in time in changing bits, as with the hammer drill it is simply necessary to lift off the machine, take out the drill and replace it with a new one, replacing the machine on the new bit; while with the reciprocating drill it is necessary to crank back the feed screw, withdrawing the bit from the hole, remove the bit from the chuck, place the new bit, and finally turn down the feed screw to bring the bit to the required position.

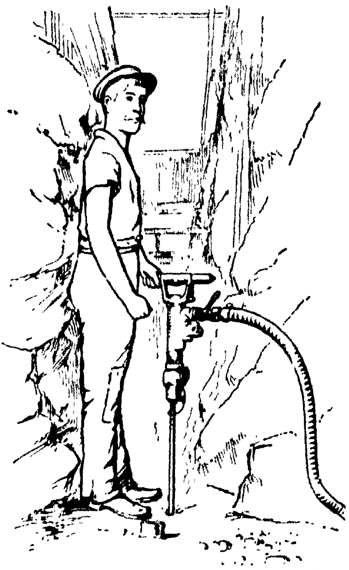


FIG. 37.—Jackhammer drill (Ingersoll-Rand).

This drill occupies a sort of middle place between the double-hand drill and the reciprocating drill, superseding each under many conditions. The double-hand drill will still be used when there is insufficient drilling

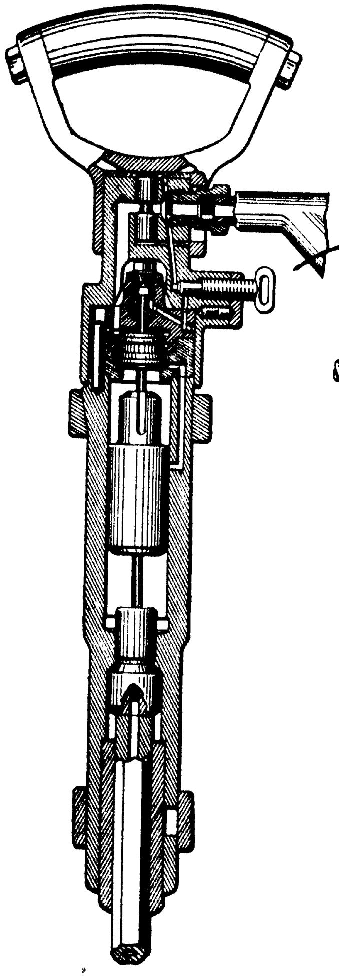


Fig. 38.—Hammer drill (Sullivan).

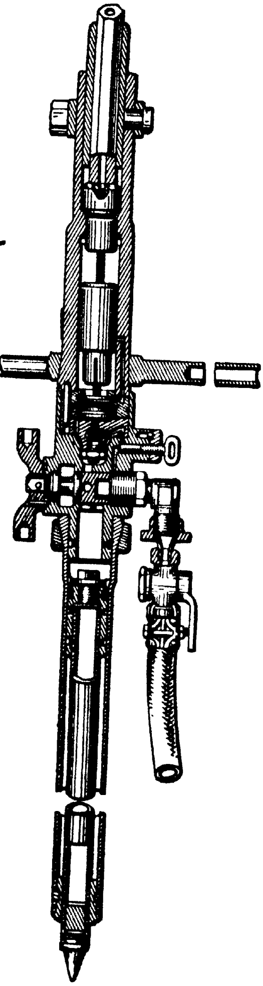


Fig. 39.—Stoping drill (Sullivan).

to be done to warrant providing an air compressor for operating power drills, but where such a machine is available there appears to be little field left for the hand drills. Similarly the reciprocating drill has been replaced upon work too heavy for hand drilling and yet within the practical limits of the hammer drill. Where power is available the hammer drill may be used advantageously for block-holing to break boulders, for trimming small outcroppings of ledge, and for following up reciprocating drills where shallow holes are required.

Several sizes of hammer drills are commonly used upon construction work, the lightest weighing from 20 to 25 lb., being capable of drilling holes to about 4 ft. in depth large enough for 7/8-in. powder, and the heaviest, weighing from 30 to 50 lb., capable of drilling holes large enough for 1-1/4-in. powder and to about 6 ft. in depth. The valve is so arranged as to be opened when pressure is exerted on the handle of the drill. When this pressure is released the valve is automatically closed.

The piston, or hammer, in the type shown in Fig. 38, rises and falls with the corresponding admission of compressed air to the cylinder, imparting to the top or head of the drill a sharp blow each time it falls. This type of drill depends upon the admission of exhaust air to the hole passing through the bit for blowing the dust and mud out of the drill-hole. A valve is provided, by means of which the operator can regulate the quantity of exhaust air admitted to the hole, so that when drilling shallow holes the quantity admitted may be relatively small, but when drilling deep holes a relatively large supply of air can be used.

The two objections to this type of drill are the vibration imparted to the operator and the quantity of dust thrown into the air, which may have some effect on the health of a person operating one of these drills continuously. The former objection is met in part by cushioning, thus reducing as much as practicable the vibration imparted to the operator. The second objection is met in part by providing for the admission of water to lay the dust. This is particularly useful in tunnel work but is not ordinarily attempted in open trench drilling.

The hammer drill has been adapted for some grades of tunnel work by mounting it on the upper end of a hollow steel cylinder provided at the bottom with a point to hold it securely in position, Fig. 39. A feed plunger moves backward and forward in the cylinder, being actuated by compressed air admitted to the cylinder through the throttle valve. When the throttle is slightly opened, air is admitted to the feed cylinder thus forcing the drill out until the bit comes in contact with the rock. Upon opening the valve further the air is admitted to the operating cylinder and the drill set in motion. The pressure of air in the feed cylinder holds the drill constantly in contact with the rock, even when drilling overhead. The feed cylinder is about 2 ft. in length. The drill is rotated by moving the rotating handle backward and forward about a quarter of a turn. When the hole has been drilled to the required depth, the throttle is closed, thus releasing the air in the feed cylinder and allowing the drill to recede slowly from the hole.

In Table 16 are given the cylinder diameters, weights, etc., of several types of hammer drills, the figures being taken from various bulletins of the Ingersoll-Rand Co. The table also gives the amount of free air required to run drills of several types and at different gage pressures. These figures have been determined by tests made from time to time with these drills.

As with the reciprocating drills, the quantity of air required to operate a battery of drills is not proportional to the number at all times, as some of the drills are running slowly or are shut down, while others are running at full speed. The quantity of air required to run from 1 to 70 of these drills may be obtained by using the multipliers given in Table 10.

TABLE 16 -DIMENSIONS, PERFORMANCE AND AIR REQUIREMENTS OF HAMMER DRILLS (INGERSOLL-RAND)

Type	A	B	C	D	E
Cylinder diam., inches	1 3/8	1 7/16 & 1 11/16	1 7/16 & 1 11/16	2	2 1/4
Stroke, inches	2 1/2	2 1/4	2 1/4	1 7/8	2
Length over all, inches	17 1/2	15	15	17 3/4	18
Depth of hole, inches	6	48	48	72	144
Weight of drill, lb	21	22	30	29 or 34	40
Size of air inlet, inches	3/8	3/8	3/8	3/4	3/4
Size of shank, inches	11/16 × 2 5/8	7/8 × 3	7/8 × 3	7/8 × 3 1/4	7/8 × 3 1/4
Starter bit, 12-in runs	5/8–7/8	1 7/16	1 7/16	1 3/4	2 1/2
Last bit		1 1/16	1 1/16	1 1/8	1 1/8
Air per min per drill, cu ft.					
Gage press., 60 lb	17	12	12	30	37
Gage press., 70 lb	21	15	15	35	43
Gage press., 80 lb.	25	19	19	39	49
Gage press, 90 lb.....	30	23	23	44	55
Gage press, 100 lb	35	27	27	48	62

Practical Limitations to the Several Methods of Drilling.—Single hand drilling is not used to a great extent in the excavation of ordinary sewer trenches. It is occasionally useful, however, in cracking boulders, and it may possibly be used to a limited extent where the ledge lies in strata in a wide trench, and is of such a nature that it can be split off readily by methods ordinarily used in quarrying. This method of drilling may in some cases be extended to holes from 3 to 5 ft. in depth, but such cases are exceptional.

Double hand drilling is commonly used where the holes are not to be deep, say from 1 to 3 ft., or where the total quantity of ledge to be excavated is relatively small, thus making it inadvisable to provide a power drilling plant. This method is also used in connection with the reciprocating drill for drilling the odds and ends of ledge where too much time would be consumed in moving the drill. It is generally not wise to attempt drilling holes more than 4 or 5 ft. in depth by this method, although if necessary they may be drilled to a depth of 10 to 15 ft. by the use of heavy hammers.

The hammer drill has changed materially the limit to which double hand drilling can ordinarily be carried with economy. This drill is not in itself particularly expensive and does not require an expensive power plant. Consequently, it is being used extensively for the drilling of shallow holes which formerly were drilled by the double hand method. Formerly it was usually wise to change from double hand drilling to steam or air drilling where the holes became from 2-1/2 to 4 ft. deep and the quantity of ledge to be excavated was large enough to warrant the use of such machinery. With the possibility of using the hammer drill, the older type of steam drill does not come into use except upon deep holes or holes in very hard ledge.

The length of holes which may be drilled with the hammer drill depends upon the character of the rock. Upon very hard rocks, occasionally a progress of not more than 1 ft. an hour, on the average, can be made, but in ordinary rocks a progress of from 3 to 5 ft. per hour may be expected.

Upon sewer excavation in Hopedale, Mass., where the quartzite encountered is extremely hard, the rates of progress with hammer and tripod drills are given in Table 17, which contains a record of several weeks continuous use of drills.

TABLE 17.—RATES OF PROGRESS PER DAY OF 9 HOURS OF STEAM AND HAMMER DRILLS WORKING IN VERY HARD QUARTZITE AT HOPEDALE, MASS., 1913

Type of drill	Avg rate	Max rate	Min rate
Hammer drill	15.2 ft.	18 ft.	13 ft.
Hammer drill	16.2 ft.	19 ft.	14 ft.
Tripod drill	15.7 ft.	24 ft.	12 ft.
Tripod drill	13.4 ft.	19 ft.	10 ft.
Tripod drill	19.3 ft.	24 ft.	15 ft.
Tripod drill.	17.2 ft.	20 ft.	14 ft.

It will be seen that the minimum rate for the tripod drill was as low as 10 ft. and for the hammer drill 13 ft. per day of 9 hours, while the maximum rates were 24 and 19 ft. respectively. The average rates obtained by the use of hammer drills were practically the same as those of the tripod drills. It should be taken into consideration, however, that the tripod drills were put upon the hard steady drilling while the hammer drills were used for the shallower and less difficult holes. This arrangement doubtless tended to equalize the output of the two types of machine, each proving economical upon its class of work.

DRILL BITS

The drill bits used with the reciprocating drill are made of round or hexagonal steel with points of many shapes. The drill bits in a set vary in length progressively ordinarily by intervals of 24 in., although these intervals are dependent upon the length of the feed screw and may vary according to the drill selected. The bits used with the hammer drill are made of hollow steel, the so-called six-point rose bit being commonly used upon construction work. The drill bits required for the hammer drill vary in length progressively by intervals of 12 in.

An instructive article by T. H. Proske, printed in *Mining and Scientific Press*, March 5, 1910, gives many practical points of value regarding the shape and sharpening of drill bits, for both reciprocating and hammer drills. The following quotation is from this article:

> "The success of almost every drilling operation depends on the selection and treatment of the bits. Too much attention cannot be given this important part of the work. If the bits have been properly formed, sharpened and tempered for the work, and if they are changed just as soon as their edges and gages are worn, the result will be found to be most economical.
>
> "For the guidance of those unfamiliar with the forms of drill bits used in the different sections, I have prepared a few drawings of those in use. A, Fig. 40, represents the square cross-bit adopted as the standard for American mining practice. It is made from either round, octagon or cruciform steel. The reason for the adoption of this form of bit as a standard will be appreciated when the three requirements of a rock-drill bit are recalled. These are 'to chisel out a hole in the rock,' 'to keep this hole round and free from rifles,' and 'to mud freely.' There is really a fourth requirement, which is 'to do as much drilling as possible before being re-sharpened.'
>
> "The different kinds of rock to be drilled affect the wear of the bit. Very hard rock will blunt the chisel and reaming edges. The softer rocks do not blunt these edges, but wear the outer sides so that it loses its gage and size, still appearing to be quite sharp. For this reason a bit that is made with a square edge and a clearance angle of 8 deg. will drill about four times as long in soft rock as a bit with round edges and a clearance angle of 16 deg., before being reduced to the size of the next bit that is to follow. Referring to A and B, Fig. 40, the latter being a round-edge bit with a clearance angle of 16 deg., it will be seen that in A the corners of the bit at the base of the bevel describe a circle that is equal to the circle that the chisel edges describe. This is as it should be, as it is impossible for the chisel edge to cut out all of the rock. The reaming edge, which is that part of the bit extending from the chisel edge to the base of the bevel, marked *a* in both A and B, must ream the outer edge of the hole and keep it

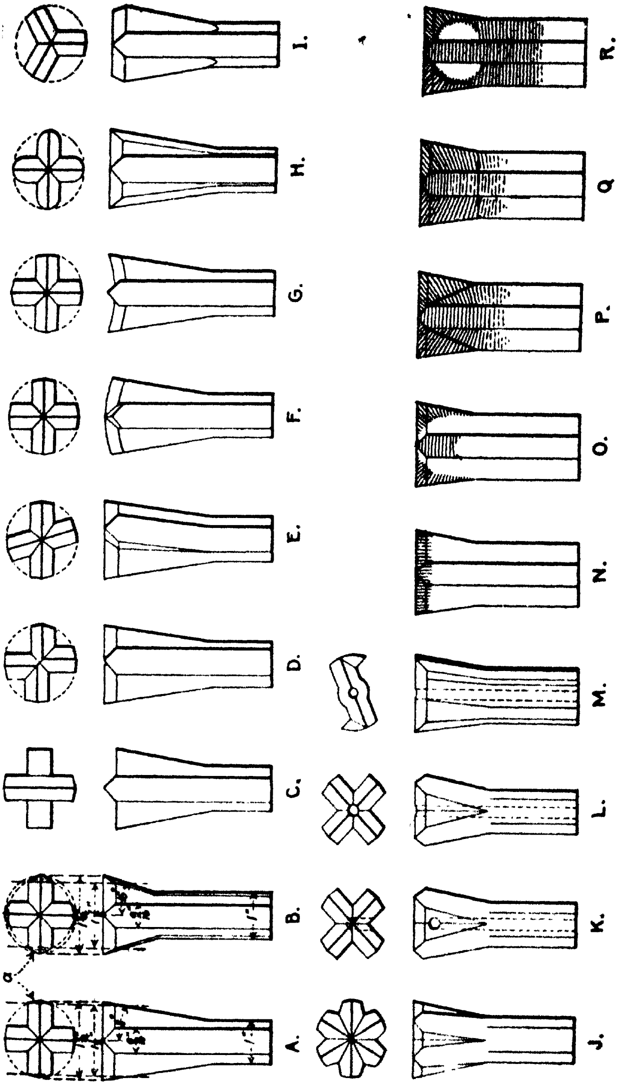


FIG. 40.—Different types of drill bits (Proske).

round and free from rifles. In B it will be noted that the circle describ by the corners of the bit at the base of the bevel is much smaller than th circle described by the chisel edges. This causes an excess of wear on th corners of the chisel edges, the bit rapidly loses its gage, as well as i efficiency, and it is almost impossible to keep the hole round. Rifles form and these cause the rotating parts of the drilling machine to break, ofte resulting in the loss of the hole.

"The angle of the bevel of the face of the bit has to do with its life as we as with the property of 'mudding' freely. It is generally accepted that this angle be 90 deg. it gives strength and permits the bit to 'mud' or thro back the cuttings from the face of the bit when the drill is pointed downward Another reason why bits such as is shown in A are preferable to thos illustrated by B is that having a long wing they are stronger and will no break so readily as does a short bit.

"The Simmons bit is shown in Fig. C. In it two of the wings are devote entirely to reaming and keeping the hole round and free from rifles.

"The Brunton bit is shown in D. The object of this bit is to obtain the advantages of the X-bit without the attendant difficulties of re-sharpening. With this bit, as in the case of the X-bit, the piston must revolve a half turn before the cutting edges will strike in the same place a second time. It is as easily re-sharpened as the regular square cross bit.

"The X-bit itself is shown in E. It is designed to prevent rifles. This the hand-sharpened cross bit would not do, but the machine-sharpened cross bit effectually accomplishes.

"F shows what is commonly termed the high-center bit. This was for many years accepted as the proper form. Since the introduction of hammer drills this bit is again finding favor. It is of especial advantage in starting a hole, the high center immediately making an impression on the rock, whereas the square-faced bit requires a flat face for ready starting. For a starting bit in hammer machines it has no equal. Here, however, its advantages over the square bit end. Used as a bit to follow the starter, it is liable to follow slips and seams in the rock, causing crooked holes, which are sometimes lost before being finished. This the square bit will not do.

"G shows a bit where the corners are in advance of the center. This is a fast cutting bit. The corners break up the rock in advance of the center and leave little for the center to do; this causes the corners to wear fast, but still not to excess when it is considered that they do most of the work. This drill will not follow slips and seams, will drill a round hole, and is easy on the drilling machine. The weak point of this form is that the leverage is so great on the corners that they are liable to break off if tempered too hard.

"H shows the round-edge bit, which is a favorite with some. In soft rock this is good, but in hard rock it permits rifles to form in the hole because there are no reaming edges.

"The T-bit shown in I gives the advantage of plenty of room for the cuttings to escape. It is, however, quite difficult to make and re-sharpen by hand. With the power-sharpener it can be made as easily as any other form.

"J shows the 'six-wing rosette' bit. It is used in hammer drills only. Of all the rosette forms of bits this has been found to be the most satisfactory.

"K shows the square cross bits when made up for hammer drills where a hole for the introduction of air or water to remove the cuttings apexes at a point back from the bevel of the bit in one of the recesses between the wings.

"L shows the same form where the hole ends in the center of the cross of the cutting edges. This form of bit is extensively used. Its faults are that a core is formed by this hole; this core fills the hole, and causes a stoppage of air and water. These cores have been known to become as much as 8 in. long and are quite difficult to remove. To clear them away the core must be burned out by heating the steel the full length of the core in a slow fire; sometimes a slow and tedious process. This difficulty is entirely overcome by the use of the bit shown in K.

"The Z-bit, M, is extensively used in Germany. In hammer drilling machines, the steel is formed in bars having a Z shape. While I show this bar straight, it is usually twisted to form a spiral. It is an easy matter to form a Z-bit on the end of such a bar. The results obtained are excellent. Holes to a depth of 16 ft. horizontal have been drilled with this form of steel. The spiral draws out the cuttings much the same as an auger.

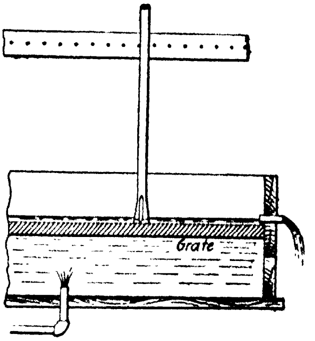


FIG. 41 —Bit tempering tank

"After a bit has been forged, it should be properly tempered as in N. O shows the result of the common method of tempering. The center of the bit is soft, while the corners are hard. When the bit is immersed in the water about an inch, the large mass of metal in the center cools more slowly than the corners since the corners have three sides exposed to the water. Perhaps the center has not chilled at all when the bit is withdrawn for annealing, and the final result is a soft-center bit, which will flatten and retard the work of drilling. P and Q show the result of trying to temper the bit with the forging heat, by plunging the whole bit into the water as soon as it is sharpened. The line of tension induced by cooling is indicated. At this place the drill will break. R shows the checking caused by first chilling the steel back of the bit and then plunging with the forging heat.

"For the purpose of tempering a bit as shown in N a tank should be provided, such as shown in section in Fig. 41. This should be about 12 in. deep by 12 in. wide, and of sufficient length to accommodate whatever number of drills are to be sharpened in a day with the machine. The water inlet should be at the bottom, and the outlet should be placed about 3/4 in. above a grate, which itself should be about 8 in. above the bottom. This permits the bit to be immersed to a depth of about 3/4 in. With a tempering tank of this construction the bit can be hardened to any desired degree. This depends on the temperature of the bit when placed on the grate. It is essential that the drill stand in a vertical position. To lean either way would cause it to harden to a greater depth on one side than on the other, causing a tension that might lead to breaking of the wings. It is best to provide a rail around the tank about the distance required to hold the shortest drill, and to drive pins about 3 in. apart in this rail. By placing the drills between these pegs they can be kept in a vertical position. When using this tank a small flow sufficient to displace the water heated by the cooling of the bits should be turned on to keep the supply always cool."

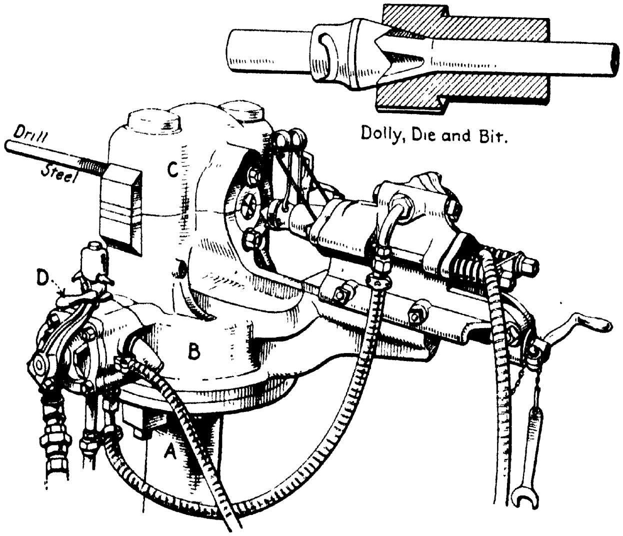


Fig. 42.—Leyner drill sharpener (Ingersoll-Rand).

Drill Sharpeners.—The recent advances made in the manufacture of rock drills are no more important than those made in the art of sharpening drills. Perhaps the greatest advance in this direction is the invention of drill-sharpening machines, in which the bits are formed in exact accordance with pre-determined designs. All bits made in machines are uniform in shape and size. The use of sharpeners has resulted in a great reduction in cost of sharpening. In an annual report, Matthew Gault, Superintendent of the Sewer Department of Worcester, Mass., states that the cost of drill sharpening has been reduced two-thirds by the use of a Leyner drill sharpener. In spite of these advantages, however, it is important not to lose sight of the great importance of proper tempering, which is probably the most essential part of the blacksmith's work, especially where rock of a great range of hardness, requiring differently tempered bits, is encounterd, as in some New England cities.

The Leyner drill sharpener is typical of such machines. The bit is formed entirely within a split conical die, Fig. 42, by a properly shaped dolly. The machine, is shown with a bit clamped in the sharpener just after the bit has been formed and the dolly withdrawn. This sharpener is operated entirely by compressed air.

The top of the sharpener consists of a heavy clamp, which holds the die and bit, and a hammer, which is built like a small rock drill and has the dolly held horizontally, as shown in the illustration. The clamping portion of the device consists of a support, A; a clamping head, B; and a yoke, C. Inside of A and B there is a large differential piston, the head within B being much the larger and receiving the air pressure on its upper surface. Two steel rods rise from this piston through the clamping head and yoke C, to which they are attached. If the handle D is turned in one direction, the air pressure is admitted to the top of the large end of the piston, holding the die and steel firmly, as shown; if the handle is turned the other way the air pressure is admitted below the small end of the piston and the yoke is raised.

The hammer cylinder, which resembles the ordinary rock drill cylinder, contains a freely moving hammer the front end of which travels in two steel bushings and strikes on the shank end of the dolly, resting in a forged steel guide flange. The hammer cylinder travels in a guide shell and may be fed backward and forward by means of a screw, thus enabling the operator to change dollies quickly. To do this the clamp bolts are loosened, the cylinder cranked back, the dolly changed and the cylinder returned to the proper position and reclamped. The sharpener may be used to form and sharpen pins, drill steel shanks, bolt and rivet heads and drill bits of any design.

COMPRESSED AIR

Useful information relating to compressed air and its use in reciprocating drills is given in Tables 18 and 19, prepared by the Ingersoll-Rand Co., which gives the following explanation of them:

"The tables will determine the amount of free air required to operate rock drills at various altitudes with air at given pressures. The tables have been compiled from a review of a wide experience and from tests run on drills of various sizes. They are intended for fair conditions in ordinary hard rock, but owing to varying conditions it is impossible to make any guarantee without a full knowledge of existing conditions. In soft material, where the actual time of drilling is short, more drills can be run with a given sized compressor than when working in hard material, when the drills would be working continuously for a longer period, thereby increasing the chance of all the drills operating at the same time. In tunnel work, where the rock is hard, it has been the experience that more rapid progress has been made when the drills were operated under a high air pressure, and it has been found profitable to provide compressor capacity about 25 per cent. in excess of requirements. There is also a distinct advantage in having a compressor of larger capacity, in that it saves the trouble and expense of moving the compressor as the work progresses, and will not interfere with the work of driving the tunnel. No allowance has been made in the tables for loss due to leaky pipes, or for transmission loss due to friction; but the capacities given are merely the displacement required, so that when selecting a compressor for the work required these matters must be taken into account."

TABLE 18.—CUBIC FEET OF FREE AIR PER MINUTE REQUIRED TO RUN ONE RECIPROCATING DRILL OF THE SIZE AND AT THE PRESSURE STATED, AT SEA LEVEL (INGERSOLL-RAND)

Gage pressure, lb	Cylinder diameter of drill												
	2 in	2¼ in	2½ in	2¾ in	3 in	3⅛ in	3 3/16 in	3¼ in	3½ in	3⅝ in	4¼ in	5 in	5½ in
60	50	60	68	82	90	95	97	100	108	113	130	150	164
70	56	68	77	93	102	108	110	113	124	129	147	170	181
80	63	76	86	104	114	120	123	127	131	143	164	190	207
90	70	84	95	115	126	133	136	141	152	159	182	210	230
100	77	92	104	126	138	146	149	154	166	174	199	240	252

Transmission of Compressed Air.—An important part of the installation of an air drilling outfit is the selection and laying of the compressed air line. It is important to provide air mains of sufficient size so that the working pressure will not fall too low. There is not the loss in power, due to reduction in pressure, which at first thought might be expected, as with a reduction in pressure there is an increase in volume. The information given in Tables 20 and 21, prepared by the Sullivan Machinery Co., gives the loss due to friction in pipes 100 ft. in length, for different diameters of pipe and volumes of air, the initial or compressor pressure being 90 and 100 lb. per square inch, respectively. To ascertain the loss in pressure at the drill, the loss in 100 ft. should be multiplied by the length of pipe in units of 100 ft.

Air Cooling and Reheating.—In an extensive line of air piping, it is very important that the air be kept dry, otherwise the freezing of the condensation from the air will cause damage to the pipes and drills. The amount of moisture that can be carried in suspension by the air increases with rise of temperature. The "aftercooler" is an instrument for lowering the temperature of air, thus precipitating the moisture and reducing the liability of freezing. It consists of a steel shell containing steel tubes through which the air is conducted. Cold water enters the cooler

TABLE 19.—MULTIPLIERS TO DETERMINE CAPACITY OF COMPRESSOR REQUIRED TO OPERATE FROM 1 TO 70 ROCK DRILLS AT DIFFERENT ALTITUDES (INGERSOLL-RAND)

Altitude above sea level, feet	Number of drills 1	2	3	4	5	6	7	8	9	10	12	15	20	25	30	40	50	60	70
	Multipliers																		
0	1.	1.8	2.7	3.4	4.1	4.8	5.4	6.0	6.5	7.1	8.1	9.5	11.7	13.7	15.8	21.4	25.5	29.4	33.2
1,000	1.03	1.85	2.78	3.5	4.22	4.94	5.56	6.18	6.69	7.3	8.34	9.78	12.05	14.1	16.3	22.0	26.26	30.3	34.2
2,000	1.07	1.92	2.89	3.64	4.39	5.14	5.78	6.42	6.95	7.60	8.67	10.17	12.52	14.66	16.9	22.9	27.28	31.46	35.52
3,000	1.10	1.98	2.97	3.74	4.51	5.28	5.94	6.6	7.15	7.81	8.91	10.45	12.87	15.07	17.38	23.54	28.05	32.34	36.52
4,000	1.14	2.05	3.08	3.88	4.67	5.47	6.15	6.84	7.41	8.09	9.23	10.83	13.34	15.62	18.01	24.4	29.07	33.52	37.8
5,000	1.17	2.10	3.16	3.98	4.8	5.62	6.32	7.02	7.61	8.31	9.48	11.12	13.69	16.03	18.49	25.04	29.84	34.4	38.84
6,000	1.20	2.16	3.24	4.08	4.9	5.76	6.48	7.2	7.8	8.52	9.72	11.4	14.04	16.44	18.96	25.68	30.6	35.4	39.84
7,000	1.23	2.21	3.32	4.18	5.04	5.9	6.64	7.38	7.99	8.73	9.96	11.68	14.39	16.85	19.43	26.32	31.36	36.16	40.84
8,000	1.26	2.27	3.40	4.28	5.17	6.05	6.8	7.56	8.19	8.95	10.21	11.97	14.74	17.26	19.9	29.96	32.13	37.04	41.83
9,000	1.29	2.32	3.48	4.39	5.29	6.19	6.96	7.74	8.38	9.16	10.45	12.26	15.09	17.67	20.38	27.6	32.9	37.92	42.83
10,000	1.32	2.38	3.56	4.49	5.41	6.34	7.13	7.92	8.58	9.37	10.69	12.54	15.44	18.08	20.86	28.25	33.66	38.8	43.82
12,000	1.37	2.47	3.70	4.66	5.62	6.57	7.4	8.22	8.9	9.73	11.1	13.02	16.03	18.77	21.64	29.32	34.94	40.28	45.48
15,000	1.43	2.57	3.86	4.86	5.86	6.86	7.72	8.58	9.3	10.15	11.58	13.58	16.73	19.59	22.59	30.6	36.46	42.04	47.47

EXAMPLE.—Required the amount of free air necessary to operate thirty 5-in. drills at 9000 ft. altitude, using to operate these drills air at a gage pressure of 80 lb. per square inch. From Table 18 we find, when operating the drills at 80 lb. gage pressure at sea level, that one 5-in. drill requires 190 cu. ft. of free air per minute. From Table 19 we also find that the factor for 30 drills at 9000 ft. altitude is 20.38; multiplying 190 cu. ft. by 20.38 gives 3872 cu. ft. free air per minute, which is the displacement of a compressor for the above outfit under average conditions, to which must be added pipe line losses, such as friction and leakage.

TABLE 20.—LOSS IN PRESSURE, IN POUNDS PER SQUARE INCH, DUE TO FRICTION IN PIPES 100 FT. IN LENGTH. GAGE PRESSURE AT ENTRANCE TO PIPE, 90 LB. (SULLIVAN)

Diam. pipe, in.	Cubic feet free air delivered per minute																													
	25	50	75	100	125	150	200	250	300	350	400	500	600	700	800	900	1000	1200	1500	1800	2000	2500	3000	3500	4000	5000	6000	7000	8000	9000	10000
1	0.33	1.3	2.92	5.19																											
1¼	0.09	0.36	0.81	1.44																											
1½	. .	0.14	0.31	0.56	0.87	1.25	2.23																								
2	.	0.03	0.07	0.12	0.19	0.27	0.48	0.76	1.09	1.48	1.94																				
2½	.	.	.	0.04	0.06	0.08	0.15	0.23	0.33	0.45	0.59	0.92	1.33	1.81	2.36																
3			.	. .		0.03	0.06	0.09	0.13	0.17	0.22	0.35	0.5	0.68	0.89	1.12	1.39	2.0													
3½	. .							.	0.06	0.08	0.1	0.16	0.23	0.3	0.4	0.51	0.63	0.9	1.41												
4								. .			0.05	0.08	0.11	0.15	0.2	0.25	0.31	0.45	0.7	1.0	1.24	1.93									
4½											.	0.04	0.06	0.08	0.11	0.14	0.17	0.25	0.39	0.56	0.69	1.07	1.54								
5	.	.											0.04	0.05	0.06	0.08	0.1	0.14	0.22	0.32	0.39	0.61	0.88								
6	.		.												0.02	0.03	0.04	0.06	0.09	0.12	0.15	0.24	0.35	0.47	0.61						
7	. .		.														0.02	0.03	0.04	0.06	0.07	0.11	0.16	0.21	0.28	0.44	0.63				
8	.		.																0.02	0.03	0.04	0.06	0.08	0.11	0.14	0.22	0.32	0.43	0.57		
10																					0.01	0.02	0.03	0.03	0.05	0.07	0.1	0.14	0.18	0.23	0.28
12																							0.01	0.01	0.02	0.03	0.04	0.05	0.07	0.09	0.11

TABLE 21.—LOSS IN PRESSURE, IN POUNDS PER SQUARE INCH, DUE TO FRICTION IN PIPES 100 FT. IN LENGTH. GAGE PRESSURE AT ENTRANCE TO PIPE, 100 LB. (SULLIVAN)

Diam. pipe, in.	Cubic feet free air delivered per minute																														
	25	50	75	100	125	150	200	250	300	350	400	500	600	700	800	900	1000	1200	1500	1800	2000	2500	3000	3500	4000	5000	6000	7000	8000	9000	10000
1	0.3	1.18	2.66	4.75																											
1¼	0.08	0.33	0.73	1.3																											
1½	. .	0.13	0.29	0.6	0.8	1.15	2.04																								
2	.	0.03	0.07	0.12	0.18	0.26	0.47	0.73	1.05	1.43	1.87																				
2½				0.03	0.05	0.08	0.14	0.21	0.31	0.42	0.54	0.85	1.22	1.66	2.17																
3						0.03	0.05	0.08	0.11	0.15	0.2	0.31	0.45	0.61	0.8	1.01	1.25	1.8													
3½									0.05	0.07	0.09	0.14	0.21	0.28	0.37	0.46	0.57	0.82	1.28												
4											0.05	0.07	0.1	0.14	0.18	0.23	0.28	0.41	0.64	0.92	1.13	1.77									
4½												0.04	0.06	0.08	0.1	0.13	0.16	0.23	0.35	0.51	0.63	0.96	1.41								
5													0.03	0.04	0.06	0.07	0.09	0.13	0.2	0.29	0.36	0.56	0.81								
6															0.02	0.03	0.04	0.05	0.08	0.11	0.14	0.22	0.32	0.43	0.56						
7																	0.02	0.03	0.04	0.05	0.06	0.1	0.14	0.2	0.25	0.4	0.57				
8																		....	0.02	0.03	0.03	0.05	0.07	0.1	0.13	0.2	0.29	0.39	0.51		
10																				...	0.01	0.02	0.02	0.03	0.04	0.06	0.09	0.13	0.16	0.21	0.2
12																							0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.08	0.1

at one end, surrounding the air tubes completely, and leaves the cooler at the other end. *It is essential that the aftercooler be placed as near the compressor as possible.*

It is sometimes desirable to remove the moisture from the air at the end of the pipe line. For this purpose a combined water trap and separator is used. It consists of a cast-iron tank with inlet and outlet openings, and a number of baffles against which the air strikes, causing a checking of its velocity which results in the moisture entrained in the air becoming collected on the baffles, whence it drips off. There is a stop cock through which the accumulated water is forced out by air pressure. The apparatus is similar to the steam separator in design and operation.

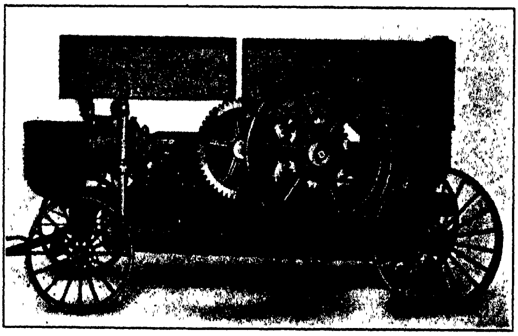


FIG. 43 -Portable air compressor (Abenaque)

When the compressed air has reached the point where it is to be used, it having lost its heat of compression in transmission or by aftercooling devices, a large saving may often be effected by raising its temperature again before it is used. For this purpose a reheater is employed, which should be placed as near the drills as possible. As the air passes through this reheater it expands in volume about 30 to 35 per cent., thus increasing its working capacity proportionally. There are many types of these reheaters, ranging from an open fire over which a rude coil of pipe is kept hot, to an elaborate device like a cast-iron house heater, except that air circulates through it instead of water or steam.

Portable Air Compressors.—There are several makes of portable air compressors for use in drilling rock in pipe trenches, in highway construction, block-holing in stone quarries and other places where the rock is too scattered or too small in quantity to warrant the use of a fixed compressor and drill plant. These outfits consist of a compressor driven usually by a gasoline engine, the whole mounted on a wagon truck as shown in Fig. 43. If the outfit is to be hauled only a short distance, a sufficient number of men can usually be taken from the trench and the truck hauled by hand, thus saving the expense of horses. Table 22 gives the general dimensions of the outfits of this class made by the Sullivan Machinery Co.

TABLE 22.—GENERAL DIMENSIONS OF SULLIVAN PORTABLE COMPRESSORS

	15 h. p.	20 h. p.
Displacement capacity, cu. ft. per min.	95	112
Terminal air pressure, lb	90	100
Diameter of gasoline engine cylinder, in.	7¾	7¾
Stroke of gasoline engine cylinder, in.	9	10½
Diameter of compressor cylinder, in.	8	8
Stroke of compressor cylinder, in	10	10
Main air receiver, in	dia. 16, length 60	dia. 16, length 60
Capacity of gasoline tank, gal	20	26
Auxiliary starting receiver, in	dia. 12, length 36	. . . . .
Front truck wheels, in	dia. 36, face 5	dia. 36, face 5
Rear truck wheels, in	dia. 44, face 5	dia. 44, face 5
Track gage	4 ft. 8 in.	4 ft. 8 in.
Axles, center to center	8 ft. 0 in.	8 ft. 6 in.
Length over all, with pole	22 ft. 0 in.	23 ft. 0 in.
Length over all, without pole	11 ft. 6 in.	12 ft. 6 in.
Width over all	6 ft. 0 in.	6 ft. 0 in.
Height over all	6 ft. 4 in.	6 ft. 11 in.
Total net weight, including pole and tools	6100 lb.	7300 lb.

Handling Rock.—Where machinery is installed for trench excavation, the rock can be handled in much the same way as earth, except that large masses may be removed by chains without the use of buckets. Where rock is handled in this way great care must be taken to insure the safety of the laborers below, and to prevent knocking out any of the trench bracing.

Where machinery is not installed the rock in shallow trenches may be thrown out by hand. This necessitates breaking it up into comparatively small pieces, either by secondary blasting or by the use of heavy sledges. For deeper trenches, a hand tripod derrick will be found useful, while, where considerable quantities of rock are to be handled from a comparatively deep trench, a portable stiff-legged derrick mounted on wheels and operated by steam hoist will generally be found to be economical.

Whenever rock is used in backfilling it should be mixed with earth so as to prevent voids which will result in future settlement. Rock should always be excavated sufficiently below the sewer, 6 in. more or less, to permit the introduction of a layer of sand or gravel to prevent localization of stress and resulting injury to the structure unless the masonry is to be built directly upon the rock in a manner to give good distribution of the local stresses.

CHAPTER VI

EXPLOSIVES AND BLASTING

Most rock excavation connected with sewer construction must be done in trench or in tunnel. In both cases the rock is firmly bound in place by the surrounding ledge, making it necessary to blast it out by the use of relatively greater quantities of explosives than are required for loosening corresponding quantities of rock in a quarry or on the surface of the ground. It is only rarely that rock can or need be quarried with the intent of producing stone suitable for building purposes, indeed it is generally desirable to shatter the stone as much as practicable to render its excavation easy and also to leave it suitable for refilling the trench.

Trenches for sewers are often so located that extreme care must be taken to prevent the injury of water pipes, conduits, and neighboring buildings and other subsurface and surface structures. This necessitates the use of small quantities of explosives, the firing of relatively few holes at one time, the use of shallow holes and most careful and effective covering of the blast to prevent the escape of flying fragments of stone.

The conditions surrounding the excavation of rock in sewer trenches and tunnels are such that it is important to give particular attention to the selection of materials and methods to be used in drilling and blasting, a matter of much importance in all rock excavation.

Dynamite is the explosive now most commonly used on sewer excavation, although gunpowder, or black powder, and contractor's powder are sometimes used, especially for breaking down frozen earth, for quarrying stone which may be readily spilt out and for cracking boulders and large pieces of ledge rock. The disruptive and shattering effects of an explosion are due to the instantaneous generation in a restricted chamber of large volumes of gases at high temperatures. Explosives are either solid, like gunpowder, or liquid like nitroglycerin, in either of which forms they occupy relatively little space. The gases generated from their combustion, however, tend to occupy a very large space and when generated in restricted space, as in blasting, the compression of these gases is so great as to cause the disruption and shattering of the rock surrounding the enclosing chamber. The power of the explosive depends upon the rapidity of the generation of gas, the volume of gas generated from a given volume of explosives, and the temperature of the gas thus formed, for the volume occupied by the gas is directly proportional to its temperature.

The gases are generated by chemical action of one of two kinds, a combination of two or more substances, as saltpeter (potassium nitrate), sulphur and charcoal, comprising gunpowder, or dissociation of one or more relatively unstable chemical compounds, as nitroglycerin into gases. Many explosives are composed of substances of both kinds, so that both combination through combustion and dissociation take place during the explosion. These two processes are described by Richard P. Dana and W. L. Saunders in "Rock Drilling" as follows:

> "The operation of blasting is conducted through the explosive force of gases generated either by explosions or by detonation. . . . An explosion is the result of combustion instituted and propagated at high temperature. Gunpowder, which is an explosive mixture, is composed of saltpeter, charcoal and sulphur. Upon being raised to the temperature of combustion, or explosion, these materials combine chemically and in so doing produce a gas. . . . It should be noticed that the chemical combination must take place progressively from grain to grain, as it were, and is not likely to be caused by a jar or shock, unless such shock should be sufficiently violent to generate a spark in the mass. The explosives are comparatively bulky . . . considering the amount of gas that they can liberate and, therefore, they require a large hole in the rock in order to introduce a sufficient amount of explosives to break it.
>
> "A detonation may be described as a disruption caused by synchronous vibration of a wave-like character, but the causes of detonation have not as yet been satisfactorily determined. There are a great many detonating compounds, including nitric derivatives such as gun cotton, nitroglycerin and dynamite, and nitrosubstitution compounds such as joveite, masurite, lyddite, securite, and a host of others. These compounds are definite chemical substances, as distinct from mixtures of several different substances, which are in such condition that a wave-like shock will cause their decomposition into gas. The speed of the wave that can produce this combustion is so great as to make the detonation of large amounts of these substances practically simultaneous, thereby causing a very much more sudden and quick shock than in the case of the explosive proper."

Gunpowder, or Black Powder.—Gunpowder is a mixture of various substances, such as saltpeter (potassium nitrate) sulphur and charcoal. A standard composition is 75 parts saltpeter, 10 parts sulphur and 15 parts charcoal. In "Earth and Rock Excavation," Charles Prelini states that when ignited the burning gunpowder develops gases amounting to 280 times its former volume and that they exert a pressure of 4.68 tons per square inch at atmospheric pressure and a temperature of 32° F. The experiments of Nobel and Able show that the temperature of the gases at the instant of the explosion is about 4000° F., from which Prelini calculates that the pressure actually exerted by the gases may be taken at 37.9 tons per square inch, which he does not consider exaggerated, as experiments have indicated a pressure as high as 42 tons to the square inch.

Black powder is used where a comparatively slow, heaving or splitting action is required, or where the material is brittle or easily fractured. By carefully selecting the size of grain, a wide range in explosive effect may be obtained. The large sizes burn slowly, exert a slow pushing force and tend to split, while the fine sizes burn more quickly, exert a shattering force and tend to break up the material into finer pieces.

The black powders are very sensitive to moisture and, therefore, should be used only in waterproof packages or where the holes are comparatively dry. Black powder for blasting purposes is carried in the market in air-tight steel casks containing 25 lb. each.

Contractors' and Judson Powders.—Contractors' powder and Judson powder are granular black powders made honeycombed and contain a small percentage of nitroglycerin. They are similar to black powder except lacking in glaze and are used for blasting gravel, hardpan, frozen earth, seamy rock and other materials too soft or yielding to be blasted with dynamite. They are fired by means of caps or explosives.

These powders are somewhat sensitive to moisture and should not be used where ventilation is poor, as in very deep trenches or in tunnels, on account of the gases liberated by the explosion.

Contractors' powder is packed in paper bags, heavily coated with paraffine and will run freely into the holes. Some grades of Judson powder are put up in cartridges.

Dynamite.—The active and determining ingredient of dynamite is nitroglycerin, a clear, yellow, oily liquid without odor but having a sweetish taste which has a specific gravity of 1.595 while that of gunpowder is about 1.0. Nitroglycerin burns quietly when ignited in the open air, explodes at a temperature of 388° F., and freezes at 41° F. When inhaled or absorbed through the pores of the body, it produces headache and sickness. Nitroglycerin is a very unstable compound, exploding very easily when subjected to detonation or percussion. The handling of nitroglycerin is therefore subject to grave danger, and for this reason it is not commonly used in blasting operations.

Nitroglycerin, being a liquid, is readily absorbed by various substances, such as sawdust, wood pulp, wood meal and kieselguhr, an earthy silicious limestone composed of small fossil shells, each of which act as a minute receptacle for the nitroglycerin. The mixture of nitroglycerin and such a substance is called dynamite. The dynamites may be divided into two classes, depending upon the character of the absorbent substance, called "dopes" in the trade, these classes being called "true" and "false" dynamites. The true dynamite is a mechanical mixture of nitroglycerin and inert absorbent, such as kieselguhr. The false dynamites are composed of nitroglycerin and absorbent mixtures which themselves enter into the chemical reaction causing the explosion and add to the strength and power which would be furnished by the nitroglycerin alone. As the nitroglycerin is merely absorbed, not undergoing chemical changes, dynamite burns, freezes and explodes much the same as liquid nitroglycerin. It is, however, less sensitive to percussion and can be handled and transported without excessive danger.

The compositions of some of the dynamites, more commonly called "powders," in common use, are given in the following list, abstracted from Gillette's "Rock Excavation."

Atlas Powder (75 per Cent.)

Nitroglycerin	75 parts
Wood fiber	21 parts
Sodium nitrate	2 parts
Magnesium carbonate	2 parts

Rendrock (40 per Cent.)

Nitroglycerin	40 parts
Potassium nitrate	40 parts
Wood pulp	13 parts
Pitch	7 parts

Giant Powder No. 2 (40 per Cent.)

Nitroglycerin	40 parts
Sodium nitrate	40 parts
Sulphur	6 parts
Resin	6 parts
Kieselguhr	8 parts

Stonite (68 per Cent.)

Nitroglycerin	68 parts
Kieselguhr	20 parts
Wood meal	4 parts
Potassium nitrate	8 parts

Dualin (40 per Cent.)

Nitroglycerin	40 parts
Sawdust	30 parts
Potassium nitrate	30 parts

Carbonite (25 per Cent.)

Nitroglycerin	25 parts
Wood meal	40½ parts
Sodium nitrate	34 parts
Sodium carbonate	½ part

Hercules (40 per Cent.)

Nitroglycerin	40 parts
Potassium nitrate	31 parts
Potassium chlorate	3½ parts
Magnesium carbonate	10 parts
Sugar	15½ parts

Vigorite (30 per Cent.)

Nitroglycerin	30 parts
Potassium chlorate	49 parts
Potassium nitrate	7 parts
Wood pulp	9 parts
Magnesium carbonate	5 parts

Horsley Powder (72 per Cent.)

Nitroglycerin	72 parts
Potassium chlorate	6 parts
Nutgalls	1 part
Charcoal	21 parts

Gelignite (62½ per Cent.)

Blasting gelatin (containing 96 per cent. of nitroglycerin and 4 per cent. of collodion cotton)	65 parts
Absorbent (containing 75 per cent. sodium nitrate, 1 per cent. sodium carbonate and 24 per cent. wood pulp)	35 parts

Forcite (49 per Cent.)

Blasting gelatin (containing 98 per cent. nitroglycerin and 2 per cent. collodion cotton)	50 parts
Absorbent (containing 76 per cent. sodium nitrate, 3 per cent. sulphur, 20 per cent. wood tar and 1 per cent. wood pulp)	50 parts

Judson Giant Powder No. 2 (40 per Cent.)

Nitroglycerin	40 parts
Sodium nitrate	40 parts
Resin	6 parts
Sulphur	6 parts
Kieselguhr	8 parts

Vulcanite (30 per Cent.)

Nitroglycerin	30 parts
Sodium nitrate	52½ parts
Sulphur	7 parts
Charcoal	10½ parts

The designation of the strength of explosives by a percentage figure is now (1914) somewhat ridiculous. In the original Nobel dynamite the dope was kieselguhr, to which various amounts of nitroglycerin were added. These amounts were recorded as percentages of the total weight of the explosives, and with dynamite of that nature this method of naming them was a good one. Even when Nobel later used nitrate of soda and wood pulp as dopes, he continued to rate the dynamite by its nitroglycerin content alone, although the substances mentioned may contribute to the force of the explosion. It was definitely ascertained at a later period that explosives like cellulose nitrates could form compositions with nitroglycerin having an explosive effect greater than that corresponding to the original dynamite prepared with the same percentage of nitroglycerin. These compounds are not rated by the amount of nitroglycerin in them but by the amount of nitroglycerin in a true dynamite of the same explosive properties. Equally great confusion exists in the trade names by which black blasting powder and blasting caps are known.

Ammonia Powder.—Ammonia powder is a form of dynamite in which a portion of the nitroglycerin is replaced by nitrate of ammonia. As the ammonia powder is somewhat slower and less violent in its action than the regular dynamite it is useful where a slow and lifting effect is desired rather than a shattering action.

Gelatin Dynamite.—Gelatin dynamite is similar to the ordinary form except that a certain portion of the nitroglycerin is replaced by a portion of gun cotton. This explosive is denser than ordinary dynamite and therefore by its use it is possible to concentrate more explosive in a hole of given size. It has the added advantage that less smoke is produced, thus making its use more desirable in tunnels. The gelatin brands are more difficult to explode and require much more powerful caps, double strength fuzes being used, to develop the full force of its explosion.

Cartridges.—Dynamite is placed on the market in the form of cylindrical cartridges or sticks, wrapped in paper and coated with paraffine to protect the dynamite from the action of water and the absorption of moisture, as well as to prevent so far as possible the escape of nitroglycerin. The cartridges are packed in wooden boxes containing about 50 lb. each. The cases should always be kept right side up that the cartridges may lie flat and thus prevent the concentration of the nitroglycerin at one end of the cartridge and its escape through the paper wrapper.

When ordering dynamite, the purchaser should specify the size which will best fill the drill hole. The sizes of cartridges of high explosives manufactured by the E. I. du Pont de Nemours Powder Co. are given in Table 23.

TABLE 23.—SIZES OF DYNAMITE CARTRIDGES (DU PONT)

Nitroglycerin dynamite, extra dynamite	Judson powder[1] Gelatin dynamite	Permissible explosives[2]	Blasting gelatin
⅞ in. by 8 in.	1 in. by 8 in.	1¼ in. by 8 in.	1¼ in. by 8 in.
1 in. by 8 in.	1¼ in. by 8 in.	1½ in. by 8 in.	1½ in. by 8 in.
1⅛ in. by 8 in.	1½ in. by 8 in.	1¾ in. by 8 in.	1¾ in. by 8 in.
1¼ in. by 8 in.	1¾ in. by 8 in.	2 in. by 8 in.	2 in. by 8 in.
1½ in. by 8 in.	2 in. by 8 in.		
1¾ in. by 8 in.	2 in. by 18 in.		
2 in by 8 in.			

[1] Judson Powder R R.P in 6-¼ lb, and 12-½ lb. bags instead of cartridges.

[2] Monobel also in 1 by 8 in and 1 1/8 by 8 in. cartridges.

Dynamite at ordinary temperatures is a soft yellowish material, easily molded in the hands and substantially free from odor. The absorbent is more or less completely saturated with nitroglycerin, which readily escapes onto the hands and, being more or less volatile, may be inhaled. It is, therefore, advisable to handle dynamite carefully and not run unnecessary chances of taking the nitroglycerin into the body, either by inhaling it or absorbing it through the pores of the skin.

Rapidity of Action.—There is a great difference in the rapidity of action of the several available explosives, coarse gunpowder being slow and nitroglycerin being one of the quickest of the explosives. The finer the grains of gunpowder, the quicker will be the action, while the dynamites increase in rapidity, in a general way, with the increase in the proportion of nitroglycerin contained in them.

As the effect of an explosion depends upon the expansive force of the gases generated, it is apparent that the gases must be closely confined in order to produce the most effective results. If the rock is compact and relatively free from seams and the holes are thoroughly and tightly tamped, the gases will be well confined and their power will be expended in effective work. If, on the other hand, the rock is full of seams, thus permitting the escape of more or less of the gases, the effective work produced by the explosives will be reduced. To overcome this difficulty, it is desirable to select a quick-acting dynamite that the gases may be produced so quickly that they will become effective before sufficient time has elapsed for their escape into the seams in the rocks. It naturally follows from these considerations that for a seamy rock, a quick-acting dynamite should be used and that for a compact, close-grained rock relatively free from seams, a slower acting dynamite or even a powder may produce satisfactory results. Dana and Saunders have given an illustration of the practical utilization of the rapidity of action of different dynamites as follows:

"Where the rock bottom does not break properly near the bottom of the holes a higher explosive or detonant can be placed at the bottom of the hole than at the top, and by placing the firing primer at or near the top of the hole the pressure of the gases can be made much greater at the bottom than elsewhere, thus producing a greater rupture. . . . When the high explosive is placed at the bottom of the hole, if the primer also be placed at the bottom, the explosion is likely to be so quick as to blow some of the charge out of the hole before the explosive at the top has an opportunity to do its work; if, however, one grade of dynamite be used throughout the depth of the hole, the detonation of the whole mass is likely to be so nearly simultaneous as not to affect the result."

Selection and Economical Use of Explosives.—By far the most common waste of explosive occurs in the use of one not suited to the work it is called upon to perform. It is an altogether too common practice for powder men to use one type of explosive for practically all kinds of work, and especially for all rock work, regardless of the physical conditions of the rock. In blasting in a quarry or in deep rock trenches, instead of changing to a higher grade of explosive after passing through the softer and weathered rock the powder man will generally use the same grade of explosive but in larger quantities, with the result that a large percentage of the energy is wasted. If, on the other hand, a high power, rapid acting explosive is used for earth and soft rocks, loss occurs not only due to the greater expense of the higher grade of explosive, but to the decreased efficiency due to the lack of propelling force.

Dr. Walter O. Snelling, in a paper before the Engineers' Society of Western Pennsylvania in 1912, presented a practical classification of the various explosives used in construction work in the order of their percussive and propellent forces, based upon results of tests made on lead blocks. This list, reprinted below, is so arranged that each explosive in the list has a higher percussive force than the explosive next below and a higher propellent force than the one above it.

Nitroglycerin.
Blasting gelatin.
65 per cent. gelatin dynamite.
60 per cent. dynamite, active dope.
50 per cent. dynamite, active dope.
40 per cent. dynamite, active dope.
30 per cent. dynamite, active dope.
40 per cent. ammonia dynamite.
40 per cent. gelatin dynamite.
Granular nitroglycerin powder.
Black powder (fine grained).
Black powder (coarse grained).

If a certain grade of explosive is being used and it is found that it does not shatter to the extent desired, then by referring to this table an explosive should be selected which appears on a line higher in the table, whereas if more propellent force is required, an explosive lower in the table should be selected.

The grade of dynamite most generally used is that known as 40 per cent. While there may be times when it will be difficult to detonate, especially in cold weather, it has the great advantage that it can be transported and handled with comparative safety. It is often advisable to use 60 per cent. dynamite upon sewer excavation because of the way in which the rock is bound in place and the necessity of shattering it to aid in handling. In tunnel work it may be necessary to use 75 per cent. dynamite for the cut shots.

Effect of Fumes.—When the gases generated by the combustion or dissociation of the explosives have spent their force in shattering the rock, they are liberated into the surrounding atmosphere. A portion of these fumes are given off from the pile of rock fragments somewhat slowly, although a very large proportion of them are liberated immediately upon the shattering of the rock. If the men return to the site of the blast and immediately begin work they will inhale more or less of the fumes, and in tunnels they are obliged to inhale large quantities, which may result in more or less prolonged headaches, dizziness, and even asphyxiation in extreme cases. Because of the discomfort caused by the fumes, it is always well to do blasting at such times as will allow utilizing the men upon other work immediately following the blast, or to do it during the noon hour or early evening, so that there may be ample time for the escape of the fumes. In tunnel work, where a supply of compressed air is almost always available, it will be found convenient to provide a valve at the shaft by means of which the air can be turned into the heading immediately after the blast. Where this is done, care should be taken always to see that the valve at the heading is open before firing.

An account of the effect of the fumes generated by the explosion of nitroglycerin was given in the *Medical Record* in 1890 by Dr. Thomas Darlington, who treated some 1500 cases of asphyxia, partial asphyxia and poisoning resulting from the use of dynamite in the construction of the Croton Aqueduct of New York City. Dr. Darlington classified the cases as acute and chronic, depending upon whether the men inhaled large quantities of gas at one time or constantly breathed air containing small quantities for a prolonged period of time. The acute cases were accompanied by giddiness, nausea, vomiting and intense headaches. Where the men were brought into sudden contact with large quantities of poisonous fumes, as just after a blast, the giddiness was immediately followed by unconsciousness, the patient presenting the usual appearance of asphyxia. This condition soon passed away, however, and was succeeded by drowsiness, languor, cold perspiration, intermittent pulse and often nausea and vomiting. The prominent symptoms in chronic cases were headache, cough, indigestion, and disturbance of the nervous system. If the patient was removed from the tunnel and put to work above ground, he steadily improved and finally recovered entirely. Nearly all the cases mentioned by Dr. Darlington recovered in spite of the fact that some of them appeared very serious at the time. When the patients seemed to be suffering from asphyxia Dr. Darlington treated them with cold applications on the head, administering subcutaneously at the same time atropine, ergotine, and other vasomotor stimulants. He recommended that workmen carry small vials of aromatic spirits of ammonia for immediate internal use in case of necessity, and stated that the inhaling of ammonia has a beneficial effect.

Use of Explosives in Wet Holes.—Where the holes can be readily pumped out and will not immediately refill with water, ordinary dynamite can be used successfully. When dynamite is immersed in water, some of the nitroglycerin is gradually displaced by water so that if the dynamite is not to be immediately exploded, there is a tendency toward a reduction in strength. It is, therefore, always desirable to fire the blast as soon after loading as possible, where the work is being carried on in the presence of water. Much protection is afforded to the ordinary dynamite cartridge by its paraffine covered paper wrapper, although this is not a complete protection. Where much water is to be encountered and the holes cannot be immediately blown, it will be found desirable to use nitrogelatin in sealed tubes in place of the true dynamite.

Freezing of Dynamite.—While pure nitroglycerin does not freeze until its temperature has been reduced to about 41° F., several kinds of dynamite freeze at temperatures of from 42° to 50° F., dependent upon the character of the absorbent, although there are "low freezing" dynamites which do not freeze until a temperature of about 32° F. is reached. When completely frozen, it is hard and rigid, a condition easily recognized, but careful examination is required to determine whether or not a dynamite cartridge is partially frozen or chilled. Dynamite which is frozen or chilled is not easily detonated. The first warning of this condition generally comes when a number of holes misfire while others appear to detonate in the ordinary manner. If, however, a careful investigation is made, it will generally be found that the charges which appeared to detonate, as usual, were far less effective, yet dynamite while chilled or frozen is exceedingly sensitive to friction and sticks should not be broken or cut while in this condition. Probably more blasting accidents occur in connection with the use (or thawing) of frozen dynamite than in any other way. It is, therefore, of the greatest importance to examine the dynamite carefully to know accurately its condition and to provide suitable means for storing it so that it may not freeze, or for properly and safely thawing it, if it has frozen. A further precaution which will be found of assistance is to blow out the holes with live steam before loading them. If after thus thoroughly blowing them out they are quickly loaded and immediately thereafter are detonated, there will be little opportunity for well-thawed dynamite to become chilled or frozen after being placed in the holes. The best results may be expected when the dynamite is at about 80° F. at the time of firing.

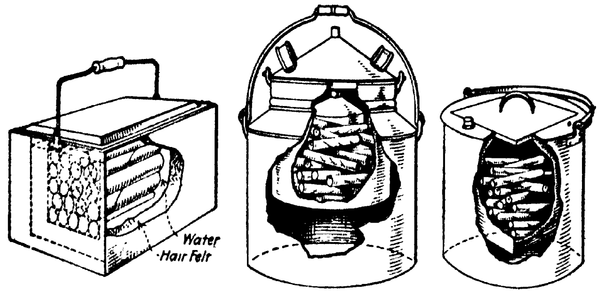
Dangers in Thawing Dynamite.—It is a common occurrence on construction work to find "powder men" of long experience who adopt dangerous expedients for thawing dynamite and who will persist in following the easy way. Precautions should be taken to prevent the leaking of the nitroglycerin from its absorbent while thawing, as this is a most frequent cause of danger. Immersion in water, especially hot water, tends to drive some of the nitroglycerin out from its absorbent by displacement by the water. Heat also drives it out. Any act which may then explode even this minute portion of nitroglycerin may cause sufficient shock to set off or explode the entire lot of dynamite which is in the process of thawing. Thawing by immersion in water is not only dangerous but objectionable on the ground that, by diminishing the quantity of nitroglycerin, it decreases the power of the explosive.

Thawing by holding over a hot stove either in the hand, upon a shovel or in a container of any sort, is dangerous, as the nitroglycerin which may thus be freed by heat is liable to premature explosion, with attendant danger of the explosion of the adjacent dynamite.

Method of Thawing Dynamite.—Frozen dynamite may be thawed with comparative safety if suitable methods are adopted and strictly followed. Valuable suggestions for suitable apparatus for thawing frozen dynamite are given in a pamphlet entitled "High Explosives," published by the E.I. du Pont de Nemours Powder Co. In this bulletin, the company states:

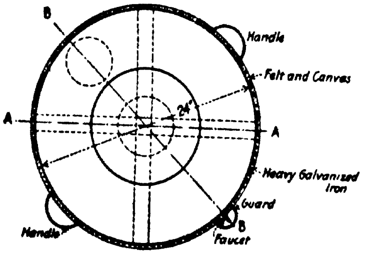
> "When large quantities of explosives are required on temporary work, an excellent device for thawing consists of a large, dry, water-tight milk can, having a half inch of sawdust in the bottom. This can should be placed in a cask or barrel containing water that has been previously heated by a jet of steam, or if steam is not available, the cask may be filled with warm water heated in some other receptacle as often as is necessary. If the water in the cask is to be heated by a steam jet, the milk can containing the dynamite must always be taken out of the cask while the water is being heated. The cask should be covered with insulating material to retain the heat. The water must never be hotter than can be borne by the bare hand."

Thawing kettles, especially designed for this work, Fig. 44, may be procured from dealers in contractors' supplies. They are designed for thawing relatively small quantities, as from one to two dozen sticks, and may be used with comparative safety provided the precautions indicated above and suitable directions, usually accompanying the kettles, are

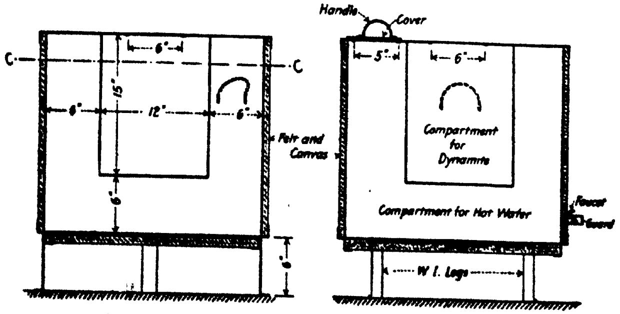


Miner's. Bradford. Catasauqua.

FIG. 44.—Commercial kettles for thawing dynamite.



Sectional Plan C-C.

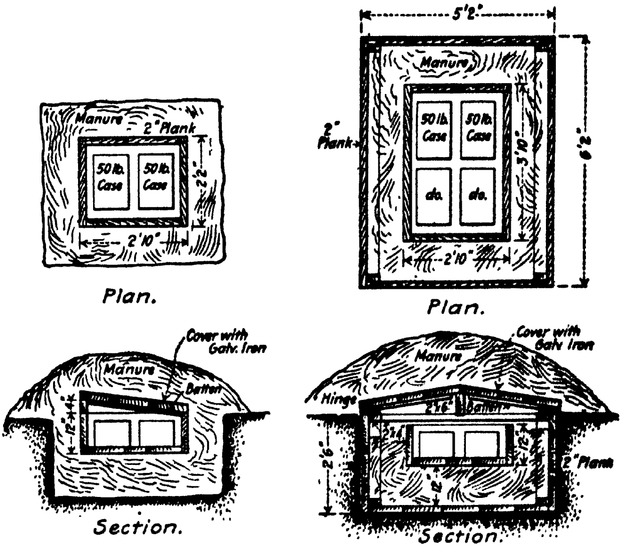


Section A-A. Section B-B.

FIG. 45.—Authors' kettle for thawing dynamite.

strictly followed. A thawing kettle used by the authors with satisfactory results is shown by Fig. 45.

Perhaps the best method of providing a supply of thawed dynamite is to place the dynamite, immediately upon delivery on the work, in a box set in a suitable pit in the ground and entirely surrounded with green horse manure, as shown in Fig. 46. Such a thawing box may provide for one, two, or possibly more, cases of dynamite at one time.



-Single- -Double-

Fig. 46.—Thawing boxes for dynamite (du Pont).

The sticks may be taken from this pit from time to time as required upon the work, care being taken not to take the dynamite out until it has had ample time for thawing if it was delivered in frozen condition. Dynamite should not be left in such a pit longer than necessary, as dampness may in time penetrate and injure it. For larger quantities, regular thaw houses should be provided. The method of heating should be indirect, and such as will under no circumstances permit the temperature to be raised above 100° F.

Loading Drill Holes.—All drill holes should be thoroughly cleaned before loading. When the hole has been drilled to its full depth, it will be found advisable to drive a wooden plug into it to prevent the entrance of dirt or water; such a plug will also aid in finding the hole. Where water and dirt have found their way into the hole, it will be necessary to blow them out with compressed air or steam, the latter being preferable in cold weather as it will thaw the ice and warm the surrounding rock, thus preventing the chilling and possibly the freezing of the dynamite which might occur if the hole were blown out with compressed air.

As the effectiveness of the blast depends upon confining the gases in the smallest space, it is always advisable to use cartridges which fill the hole. A space between the cartridge and the walls of the hole filled with air or water will have a cushioning effect upon the explosive.

The proper quantity of powder to be used for a blast must be determined by judgment and experiment. It is always wise to begin work by loading cautiously, increasing the charge upon successive blasts, if found necessary.

Exploders and Fuses.—Black powder may be exploded by the ordinary blasting fuse ignited by a match, or it may be set off by an electric exploder of low power.

For exploding contractors' powder or dynamite, a powerful shock is required, for which purpose either electric fuzes or blasting or fulminating caps are provided. The caps are made of copper shells 1/4 in. in diameter and about 1 in. long, loaded with a little fulminate of mercury and carefully sealed. The fulminate of mercury occupies only about 1/4 in. of the closed end, while the balance of the shell serves to hold the fuse. The electric fuze consists of a special cap containing fulminate of mercury, as in the blasting cap, and in addition, two electric wires projecting through a sulphur plug and connected by a platinum wire which becomes heated to a red heat by the current of electricity used, and thus explodes the fulminate of mercury.

In selecting exploders, care should be taken to purchase only those which are amply strong for the dynamite being used. In shallow holes one fuze only will generally be used and that will be placed in the top, or next to top, stick. Where deep holes are used, fuzes should be placed about 5 ft. apart. The following instructions for priming dynamite and other high explosive cartridges are given in a bulletin published by the E.I. du Pont de Nemours Co.:

"To prime a dynamite or other high explosive cartridge with blasting cap and safety fuse, make a hole in the end of the cartridge after unfolding the paper shell, or in the side of the cartridge near one end, with a small pointed stick about the diameter of a lead pencil. This hole should not be much larger in diameter than the blasting cap, for an air space around it always detracts from the force of the shock that a detonating blasting cap gives the explosive surrounding it. The best results will be obtained if the blasting cap is pointed straight down into the primer cartridge.

"When the blasting cap has been put in the end of the cartridge, the paper must be folded carefully about the safety fuse, and tied securely with a piece of string. When it is inserted in the side of the cartridge near the end, the safety fuse is held in position by tying it to the cartridge with a double loop of string.

"If the work is wet, cover the safety fuse where it enters the blasting cap with soap or tallow to prevent water getting into the blasting cap. Oil or thin grease should never be used for this purpose, as they may penetrate the safety fuse, and destroy the efficiency of the powder in it.

"The correct way to prime a high explosive cartridge with an electric fuse is to follow the same method as when fuse and blasting cap are used. The common custom of taking one or more loops, or half hitches, around the cartridge with the wires themselves, after inserting the electric fuze cap in a hole made diagonally in the side of the cartridge near one end is always to be condemned. The principal objection is that the looping of the wires is very likely to break the insulation, causing short circuits, or leakage of current in wet work. Sometimes the wires themselves are broken."

When charging, the sticks of dynamite should be pressed firmly into place with a wooden tamper, having no metal parts. Where the holes are practically dry, it will be found advantageous to put a few slits in the side of the dynamite wrapper so that the cartridges may be pressed into the hole in such a way as to fill it completely. If the holes are wet, the cartridges should not be slit unless gelatin dynamite is being used. Care should be taken in pushing the top cartridge into place not to disturb or displace the exploder or damage the fuse or the connecting wires.

Stemming and Tamping.—Explosives containing nitroglycerin, because of the rapidity of their action, will shatter the rock on which they rest, even in the open air. This is illustrated in the method of blasting by "mudcaps," or dobe blasting, the air acting as an anvil. To secure effective results, however, in the blasting of drill holes, it is necessary that the dynamite be closely confined in the bottom of the hole and that the balance of the hole be filled with some suitable material, well compacted above it. The process of compacting both the dynamite and superimposed earth is called "tamping," and it has been customary to speak of the earth packing also as "the tamping," "tamping material" or even as "tamping." To avoid confusion, the United States Bureau of Mines has suggested the term "stemming" for the tamping material, a term which may well be adopted.

The best materials for stemming are moist loam, clay or sand. In some cases it has been found advisable to use plaster of Paris, the hole being completely filled with the moist plaster which, when set, forms a very hard and tight stemming. The authors have used for stemming, in holes which are horizontal, or which point up, molded sticks of clay, dried in a warm room after molding, similar in size to dynamite cartridges. These are readily placed in the holes, pushed into position and broken up by moderate pressure on the tamping sticks. Tamping bags made of paper in which the stemming can be placed are upon the market.

After the last cartridge has been pressed into position, from 2 to 4 in. of stemming should be placed in the holes and carefully tamped by the use of gentle pressure, care being taken not to injure the fuse or to strip the electric wires. After about 6 in. of stemming has been pressed securely into place above the top cartridge, considerable pressure may be used in tamping the stemming, which is dropped into the hole, little by little, until it is filled. It is, however, sufficient to tamp by hand, any additional pressure being unnecessary and dangerous. Tamping should never be done with any metal bar or a wooden bar containing metal.

Unloading Holes.—Unfortunately, it is sometimes necessary to remove the stemming and dynamite from loaded holes because of failure to explode, due perhaps to broken wires, defective caps or other causes which are many times not known. In such cases, the cap is in the dynamite and may readily be fired by an accidental blow and it is also possible to ignite the dynamite directly. The process of unloading is, therefore, a delicate one, to be carried out only with the greatest care. The stemming should be carefully removed by means of a copper spoon until the hole has been cleaned to a sufficient depth to permit placing another cartridge and exploder on top of the charge already in the hole. The hole should then be refilled and tamped and fired. The firing of the upper charge will almost always set off the lower one. If the dynamite must be removed from the hole it can be done with the copper spoon, but it is a dangerous proceeding and should never be attempted if it can possibly be avoided.

Disposal of Unexploded Dynamite.—It occasionally happens that unused dynamite must be disposed of. The proper method of doing this is to split the cartridges, spread out the dynamite in a thin sheet and burn it in the free atmosphere. This can be done with comparative safety, although great care must be exercised to take reasonable precautions. The presence of an exploder in dynamite to be thus burned may prove a source of great danger.

Blasting Machines.—Electric fuzes are ignited by means of blasting machines, commonly called "batteries," concerning which a bulletin entitled "Blasting Supplies," published by the E.I. du Pont de Nemours Powder Co., gives much valuable practical information. Two sizes of batteries are made by this company, the specifications of which are given in Table 24.

The methods of construction and operation of these batteries are illustrated in Fig. 47. This battery is of the push-down type, which means that the charge of electricity is released and sent through the leading wires and explodes at the end of the downward stroke. A battery firing at the end of the upward stroke is also made.

TABLE 24.—DATA RELATING TO BLASTING MACHINES

	Size A	Size B
Posts, No.	2 only	2 unless ordered with 3
Capacity	1 to 10 Electric fuzes	1 to 30 Electric fuses
Dimensions	7 in. × 8 in. × 14 in.	7 in. × 10 in. × 18 in.
Net weight	20 lb.	25 lb.

"In the accompanying illustration, the parts marked 8 and 9 are field magnets, which are energized by the current from the revolving armature 16. The teeth of the armature pinion engage with the rack bar 1, and by clutching also engage with the armature shaft on the downward stroke (only) of the rack bar. 4 is the contact spring which, when struck by the bottom of the descending rack bar, breaks the contact between two small platinum bearings, one on the upper face of the contact spring and the other on the under side of the bridge 5, and in this way throws the entire current through the 'outside' circuit, that is, leading wire, electric fuzes and connecting wire; 15 is the commutator.

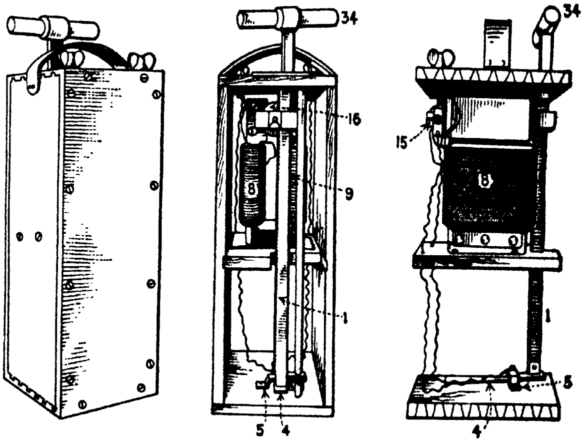
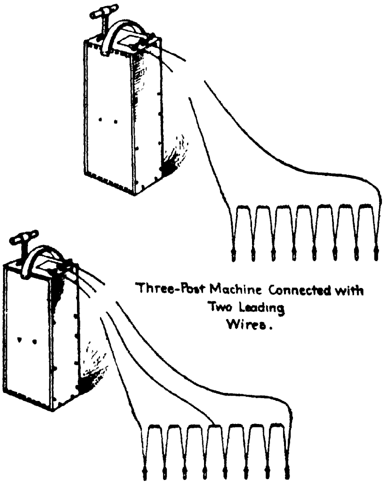


FIG. 47.—Blasting batteries (du Pont).

"To operate the push-down blasting machine, lift up the rack bar by the handle 34 to its full extent, and with one quick, hard stroke push it down to the bottom of the box with a *solid thud*. As the rack bar approaches the bottom, it becomes more difficult to operate, because of the 'building up' of the blasting machine; but the speed of the thrust should not be diminished, because the finish of the operation is just as important as the start."

The fuzes are connected in series, as illustrated by Fig. 48, and the lead wires are extended to the point where the battery is to be applied. Extreme care should be exercised to make sure that all connections are bright and tightly twisted and that the bare wire does not touch the ground or that one bare wire does not touch another. Well covered battery wire should be used for leading wires and when the covering has been damaged, new wire should be substituted immediately to avoid short circuits.

The two free ends of the lead wires are not connected with the battery until the last thing, after all persons are at a safe distance, and immediately before firing. The rack bar is then drawn up to its full height and then quickly and vigorously pushed down, thus causing a discharge of electricity of high potential to pass through the wires, which heats the fine platinum wires in the fuzes and thus ignites the fulminate of mercury, which explodes, detonating the charge of dynamite.



Three-Post Machine Connected with Two Leading Wires.

Three-Post Machine Connected with Three Leading Wires.

FIG. 48.—Methods of connecting battery (du Pont).

The battery should always rest securely on a substantial footing so that it will not move when the bar is pushed down and thus impair the force of the blow. The bar should be pushed down by a quick, hard blow, so as to generate the maximum strength of current.

A battery should never be overloaded by connecting too many holes with it or by using unnecessarily long leads, as such an overload may reduce the strength of the current sufficiently to prevent the firing of some or all of the charges.

It is well to test a battery at frequent intervals to make sure that it is in good working condition, and incidentally such a test is serviceable in showing the operator how hard a blow is necessary to produce the desired strength of current. A very convenient and satisfactory method of testing is to insert in a circuit of the usual length and size of wire an electric lamp which will fail to light up if the current is weak, will light only faintly if the current is moderately strong, but will become momentarily white if the current is strong and suitable for use. The battery may be tested by firing a number of exploders buried in the ground and wired up in the usual way.

The battery should always be kept in the best of repair and dry, for every failure to fire is a source of danger and of expense.

Shipment and Storage of Explosives.—The authors are indebted to the U. S. Bureau of Mines for the following sections, written by Col. B. W. Dunn, and extracted from its Bulletin 17:

"**Responsibility to Public.**—A responsibility to the public rests upon both manufacturers and common carriers to secure the safe delivery at destination of explosives, and it is the duty of the owners of explosives to store them safely.

"**Federal Law and Interstate Commerce Commission Regulations.**—Under authority granted by Congress, the Interstate Commerce Commission has made regulations binding upon shippers and common carriers, for the transportation of explosives in interstate commerce, and the penalty of a possible fine of $2000 and 18 months' imprisonment is prescribed by law for a violation of any of these regulations.

"The shipper must know and certify on his shipping order that the explosive offered by him is in a proper condition for safe transportation and that it is packed and marked as required by the regulations. To perform this duty the shipper should be thoroughly familiar with all requirements pertaining to his shipment. A copy of the regulations can be obtained by application to the railway agent, whose duty it is to furnish them to shippers.

"**Explosives in Baggage or Household Goods.**—Persons are sometimes tempted to pack explosives for shipment with their baggage on passenger cars, or with their household goods for shipment by freight. To do this is a criminal act that endangers the lives of the innocent and unsuspecting persons who have to handle these packages, and that subjects the guilty shipper, when detected, to arrest and prosecution. The Federal law (section 236) prescribes an imprisonment of 10 years for anyone convicted of this crime when death or bodily injury results from the illegal transportation of explosives. When no injury results the maximum is 18 months imprisonment and a fine of $2000.

"**Magazine Buildings.**—Explosives should be protected as far as practicable during storage against heat, moisture, fire, lightning, projectiles, and theft. The buildings should therefore be weatherproof, covered by fireproof and bulletproof material, well ventilated, in secluded locations, and not exposed to fire risk from grass or underbrush. Lightning protectors are best placed on a line of supports encircling the building and 20 to 30 ft. distant from it."

Isolation of Magazines.—Bulletin 17 of the U. S. Bureau of Mines also calls attention to the investigation made by the American Railway Association jointly with a committee appointed by the manufacturers of explosives, concerning the dangers that attend the location of storage magazines in too close proximity to railway property. Notwithstanding the difficulties experienced in getting reliable information, they succeeded in collecting notes covering 130 explosions. With this information platted in the form of curves they determined the distances by which storage magazines should be separated from inhabited dwellings and railways. For such magazines as are guarded by an efficient barricade or by natural protection, the distances as determined by this committee are as shown in Table 25. For such magazines as are not protected by an efficient barricade or otherwise, the distances should be doubled.

TABLE 25.—MINIMUM DISTANCES BETWEEN BARRICADED MAGAZINES AND RAILWAYS OR INHABITED DWELLINGS

(From Bulletin 17, Bureau of Mines, p. 65)

Quantity of explosives stored (lb.)	Proposed American distance (ft.)		Quantity of explosives stored (lb.)	Proposed American distance (ft.)	
	Inhabited buildings	Public railway		Inhabited buildings	Public railway
50	120	70	10,000	890	535
100	180	110	20,000	1,055	635
200	260	155	30,000	1,205	725
300	320	190	40,000	1,340	805
400	360	215	50,000	1,460	875
500	400	240	60,000	1,565	940
600	430	260	70,000	1,655	995
700	460	275	80,000	1,730	1,040
800	490	295	90,000	1,790	1,075
900	510	305	100,000	1,835	1,100
1,000	530	320	200,000	2,095	1,255
1,500	600	360	300,000	2,335	1,400
2,000	650	390	400,000	2,555	1,535
3,000	710	425	500,000	2,755	1,655
4,000	750	450	600,000	2,935	1,760
5,000	780	470	700,000	3,095	1,855
6,000	805	485	800,000	3,235	1,940
7,000	830	500	900,000	3,355	2,015
8,000	850	510	1,000,000	3,455	2,075
9,000	870	520			

"It should be understood that the proposed distances given in the above table have not yet been sanctioned by law. Whenever it becomes necessary, however, for a court to decide what would be a reasonable distance in a locality where such a distance is not specified by law, common practice would require resort to the testimony of experts. The above table represents the combined judgment of the best experts available, after an honest and prolonged study of all available data. It is probable, therefore, that the table will be accepted as a guide and that any person maintaining a storage magazine at distances less than those prescribed by it will be subject to successful prosecution before the courts for the maintenance of a public nuisance. It will be advisable, therefore, for all interested parties to see at the earliest possible moment that their magazines are located in accordance with the above table. It is understood, of course, that, in any locality where the law on this subject is now specific, the law must be the guide.

"**Care of Magazines.**—Magazines should be kept clean and in thorough repair. Grounds around them should be kept clear of leaves, grass or other materials that might feed a fire. These words should be conspicuously posted on them: "Explosives—dangerous. No shooting allowed." The sweepings should be thrown in water or taken to a safe distance and destroyed. In case floors become stained with nitroglycerin, cover the stains with dry sawdust, sweep up, and remove the sawdust. Then scrub the stains thoroughly with a hard brush and a solution of one-half pound of sulphide of sodium or sulphide of potassium in 1/2 gal. of wood alcohol. Do not allow in the magazine any tools other than a wooden mallet and wooden wedge or a phosphor-bronze chisel, and a screw driver to be used only for removing screws.

"Do not open dynamite boxes with a nail puller or powder cans with pick axes. Remove all explosives from a magazine before repairing it. Do not store detonators with explosives. Do not open packages of explosives in a magazine. Issue first the oldest explosives on hand. Do not store dynamite boxes on end, as this increases the danger of nitroglycerin leaking from the cartridges. Persons receiving packages of explosives sent by rail should examine them carefully to discover ruptures or other serious damage received during transit."

Cost of Explosives.—The cost of explosives varies greatly in different localities and at different times. However, to give the reader a rough idea of such cost, Table 26 has been prepared giving net prices current in Massachusetts on January 1, 1914, and Table 27 gives a similar list of electric fuze prices.

TABLE 26.—DYNAMITE PRICE LIST (PER 100 LB.) APPLICABLE TO MASSACHUSETTS, JANUARY 1, 1914

(From Geo. H. Sampson Co., Boston)

Quantity	[1]20%	40%	50%	60%	75%
Car load lots	$10.00	$12 00	$13.20	$14.40	$16.20
2000 lb. or over	12.00	14.00	15.20	16.40	18.20
Less than 2000 lb	12 75	14.75	15.95	17.15	18.95

[1] Low freezing dynamite (nitroglycerin).

Note.—For team deliveries in the city of Boston, Mass., and its suburbs in lots of 300 lb. and not less than 50 lb. add 2c. per lb. to the above.

TABLE 27.—ELECTRIC FUZE PRICE LIST (PER 100) APPLICABLE TO MASSACHUSETTS, JANUARY 1, 1914

(From Geo. H. Sampson Co., Boston)

	Single strength	Double strength
Cotton-covered 4 ft. wires	$3 00	$3.50
Cotton-covered 6 ft wires	3 54	4.04
Cotton-covered 8 ft. wires	4 08	4.58
Cotton-covered 10 ft. wires	4.62	5.12
Cotton-covered 12 ft wires	5.16	5 66
Cotton-covered 14 ft. wires	5 70	6.20
Cotton-covered 16 ft. wires	6 24	6.74
Cotton-covered 18 ft wires	6 78	7.28
Cotton-covered 20 ft wires	7 32	7 82

10 per cent. discount on orders for less than one thousand. 15 per cent. discount on orders for one thousand and less than five thousand. 25 per cent. discount on orders for five thousand or more.

Terms 30 days or 2 per cent. off for cash in 10 days. Freight not allowed on exploders.

Most sewer trenches are so shallow that few of the holes are deep and most of them require (or permit) the use of only one to four sticks, or from 1/2 to 2 lb., of dynamite. Therefore, a much greater number of fuses, or exploders, are used than upon work permitting the use of deep holes and heavy charges.

Upon the excavation of about 4000 cu. yd. of rock, varying from soft and seamy schist to very hard and brittle granite and trap, in shallow and narrow sewer trenches, where much of the ledge was encountered some distance below the surface of the street, the authors used from 1.76 to 3.6 fuzes per cubic yard of rock excavated, or an average of 2.5, equivalent to 1.25 to 2.57 (averaging 1.58) fuzes per pound of dynamite used. Upon this work, an average of 1.58 lb. of dynamite were used for every cubic yard of rock excavated. Assuming that 40 per cent. dynamite was used and that it cost $16.75 per 100 lb. (including team deliveries) and that four double-strength fuzes were used, costing $3.15 per hundred, the cost of explosives per cubic yard of rock excavated would be as follows:

Dynamite.	1.58 lb.	at $0.1675 =	$0.2645
Fuzes......	2.5	at 0.0315 =	0.078
Total			$0.342

CHAPTER VII

QUANTITY AND COST OF EXCAVATION

In a general way the cost of a trench is proportional to the quantity of material excavated. This, however, is subject to many qualifications. For example, the cost of sheeting, bracing and pumping will be about the same whether the trench is of the exact width needed or a foot or two wider. The cost of picking, shovelling, backfilling, and hauling surplus material to the dump, however, will be closely proportional to the quantity of material actually excavated. In some cases it may prove economical to open the trench wider than is actually necessary for the structure, so that certain types of machinery may be employed. Upon some small works, also, trenches are sometimes made so narrow that the men cannot work in them to advantage.

The design of masonry sewers may affect the cost of construction materially by requiring wide trenches; this is the case where some of the so-called aqueduct sections are used, while if circular, semi-elliptical or rectangular sections are employed, the quantity of excavation may be less. Where concrete sewers are to be built it may sometimes prove economical to fill in some extra concrete rather than to dig the trench wide enough to put in outside forms.

The character of material to be excavated usually has a marked effect upon the width of the trench. In hardpan and dry clay, the banks may stand without bracing, thus making it possible to dig the trench of practically the width of the structure to be built, while the same sewer built in a trench in quicksand, running sand, or gravel may require heavy timbering. To form a conception of this difference let it be assumed that two sewers of 6 ft. outside diameter are required in trenches 28 ft. in depth, shown in Fig. 52, and that one is to be built in loose gravel and the other in hardpan which does not require timbering. The quantity of excavation required in a hardpan trench, carried down with vertical banks, will be 168 cu. ft. per linear foot, and the extra excavation required by the sheeting and bracing in the gravel trench will be 33-1/3 cu. ft., equivalent to an increase of 19.8 per cent.

In rock excavation it is very difficult to excavate exactly to the line theoretically required. Many times the excess of excavation will be very large, on account of the inclination of the strata of rock excavated, and the tendency of this rock to slide into the trench and to break wide.

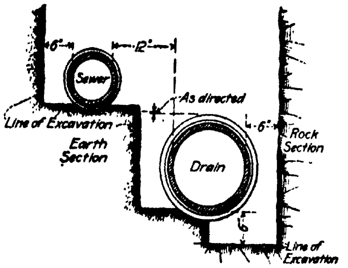


FIG. 49.—"Lines of Excavation," Hopedale sewerage system.

To provide for these uncertainties and prevent controversy as to the quantity of excavation to be paid for on contract work it is customary to prescribe certain limits to which the quantity to be paid for shall be calculated, but the contractor may, if necessary, excavate beyond these and if the structure can be built in narrower excavation he is not required to excavate the full width shown upon the drawing. Such a specification may be worded as follows:

> "The quantity of earth excavation to be paid for shall be the number of cubic yards of material . . . that would have been removed if the excavation were exactly to the depth of the bottom of the masonry or barrel of the sewer pipe, and to the width shown on the drawings by the lines of excavation."

This method is illustrated by Figs. 49 and 50.

Another method of meeting this situation, which is looked upon with much favor by some engineers, is to provide in the contract that earth excavation shall be paid for per linear foot of sewer constructed. This is an excellent method, provided the preliminary engineering has been done with sufficient care and thoroughness so that there is no possibility of a change in plans. Under this method prices are not usually taken for excavation at different depths, as where prices are taken per cubic yard of excavation, although there is

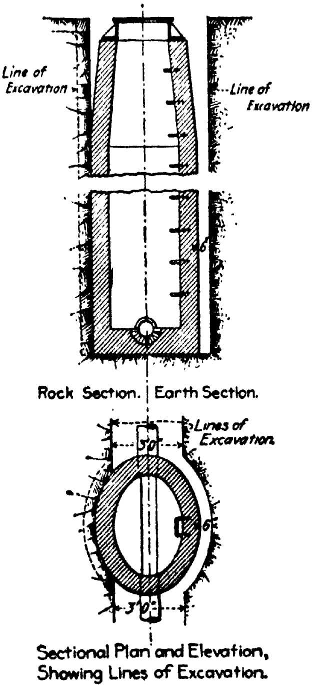


FIG. 50.—"Lines of Excavation" for manhole, Hopedale sewerage system.

no reason why this precaution could not be taken as an alternative to be used in case of changes in depth or width of excavation.

Under such contracts as those described it makes comparatively little difference what limits of excavation are prescribed provided the contractor understands the limits in advance of making his bid. It is then simply a matter of computation to determine the price which he should bid under the stipulations of the contract, for the quantity of excavation which he thinks it will be necessary to remove. This adjustment, however, is a matter of vital importance and should not be overlooked by bidders, or by engineers who are making estimates of the probable cost of work.

The quantity of excavation required for trenches from 1 to 26 ft. in depth, suitable for sewers from 6 to 24 in. in diameter is given in Table 28. The quantities given in this table are computed for the standard trenches shown in Fig. 110, Chapter XI.

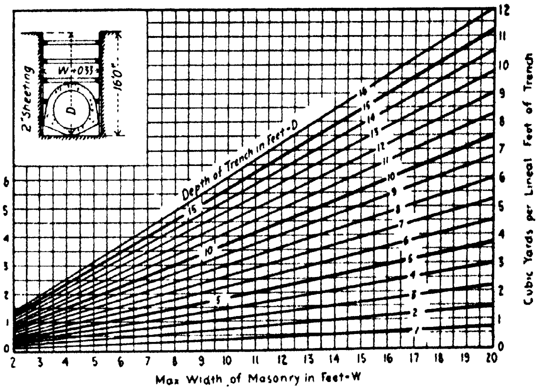


FIG. 51.—Theoretical quantity of excavation for trenches 1 to 16 feet deep, for sewers of 5 to 20 ft. outside diameter.

As pointed out by Marston and Anderson and discussed in Volume I, page 331, it is desirable to narrow the bottom of the trench to the width actually required for the pipe and jointing, by leaving square shoulders on both sides to carry a large portion of the load due to the superimposed backfill, thus reducing the load on the pipe. This reduction in excavation, however, probably will not be accompanied by a corresponding reduction in cost, for it will be offset by added expense due to shaping the bottom and working in the restricted trench. In fact, the cost may be somewhat increased but it seems probable that any such increase will be justified by the reduced danger of damage to the sewer from excessive load.

The quantity of excavation required for trenches for masonry sewers from 1 to 40 ft. in depth and from 4 to 20 ft. in width may be obtained from Figs. 51, 52 and 53. These diagrams are based upon the assumption that the top set of sheeting will be 11 or 12 ft., the bottom set 16 ft., and the intermediate set 12 ft. in length. They are computed for heavy trenches using 10 × 10-in. rangers and braces. The sheeting is assumed to be 2 in. in thickness.

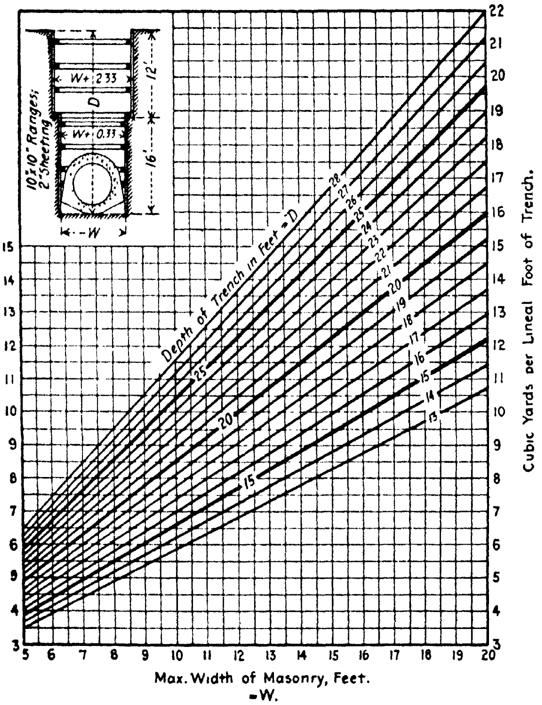


FIG. 52.—Theoretical quantity of excavation for trenches from 13 to 28 ft. deep for sewers of 5 to 20 ft. outside diameter.

The quantities of excavation obtained by the use of these diagrams should be considered as approximate only, as special calculations will be necessary for each individual case where exact quantities are to be determined.

TABLE 28.—CUBIC YARDS OF EXCAVATION PER LINEAR FOOT OF TRENCH; DEPTHS 1 TO 26 FT.; PIPES 6 IN. TO 24 IN. DIAMETER

Depth feet	6 to 12 in			15 in.			18 in			20 in.			24 in.		
	Width of trench		Excav. cu. yd per lin ft	Width of trench		Excav. cu. yd per lin ft	Width of trench		Excav cu. yd per lin. ft	Width of trench		Excav. cu. yd. per lin. ft	Width of trench		Excav. cu. yd. per lin. ft.
	Bottom	Top		Bottom	Top		Bottom	Top		Bottom	Top		Bottom	Top	
	ft in	ft in		ft. in	ft in.		ft in	ft in		ft in.	ft in		ft. in.	ft. in.	
1	3—0	3—0	0.11	3—3	3—3	0.12	3—6	3—6	0.13	3—8	3—8	0.14	4—0	4—0	0.15
2	3—0	3—0	0.22	3—3	3—3	0.24	3—6	3—6	0.26	3—8	3—8	0.27	4—0	4—0	0.30
3	3—0	3—0	0.33	3—3	3—3	0.36	3—6	3—6	0.39	3—8	3—8	0.41	4—0	4—0	0.44
4	3—0	3—0	0.44	3—3	3—3	0.48	3—6	3—6	0.52	3—8	3—8	0.54	4—0	4—0	0.59
5	3—0	3—0	0.56	3—3	3—3	0.60	3—6	3—6	0.65	3—8	3—8	0.68	4—0	4—0	0.74
6	3—0	3—0	0.67	3—3	3—3	0.72	3—6	3—6	0.78	3—8	3—8	0.82	4—0	4—0	0.89
7	3—0	3—0	0.78	3—3	3—3	0.84	3—6	3—6	0.91	3—8	3—8	0.95	4—0	4—0	1.04
8	3—0	3—0	0.89	3—3	3—3	0.96	3—6	3—6	1.04	3—8	3—8	1.09	4—0	4—0	1.19
9	3—0	3—1	1.01	3—3	3—4	1.10	3—6	3—7	1.18	3—8	3—9	1.24	4—0	4—1	1.35
10	3—0	3—2	1.14	3—3	3—5	1.23	3—6	3—8	1.33	3—8	3—10	1.39	4—0	4—2	1.51
11	3—0	3—3	1.27	3—3	3—6	1.37	3—6	3—9	1.48	3—8	3—11	1.54	4—0	4—3	1.68
12	3—0	3—4	1.41	3—3	3—7	1.52	3—6	3—10	1.63	3—8	4—0	1.70	4—0	4—4	1.85
13	3—0	3—5	1.54	3—3	3—8	1.67	3—6	3—11	1.79	3—8	4—1	1.87	4—0	4—5	2.03
14	3—0	3—6	1.69	3—3	3—9	1.81	3—6	4—0	1.94	3—8	4—2	2.03	4—0	4—6	2.20
15	3—0	3—7	1.83	3—3	3—10	1.97	3—6	4—1	2.11	3—8	4—3	2.20	4—0	4—7	2.38
16	3—0	3—8	1.98	3—3	3—11	2.12	3—6	4—2	2.27	3—8	4—4	2.37	4—0	4—8	2.57
17	3—0	3—9	2.12	3—3	4—0	2.28	3—6	4—3	2.44	3—8	4—5	2.55	4—0	4—9	2.75
18	3—0	3—10	2.28	3—3	4—1	2.44	3—6	4—4	2.61	3—8	4—6	2.72	4—0	4—10	2.94
19	3—0	3—11	2.43	3—3	4—2	2.61	3—6	4—5	2.79	3—8	4—7	2.90	4—0	4—11	3.14
20	3—0	4—0	2.59	3—3	4—3	2.78	3—6	4—6	2.96	3—8	4—8	3.09	4—0	5—0	3.33
21	3—0	4—1	2.76	3—3	4—4	2.95	3—6	4—7	3.14	3—8	4—9	3.27	4—0	5—1	3.53
22	3—0	4—2	2.92	3—3	4—5	3.12	3—6	4—8	3.33	3—8	4—10	3.46	4—0	5—2	3.73
23	3—0	4—3	3.09	3—3	4—6	3.30	3—6	4—9	3.51	3—8	4—11	3.65	4—0	5—3	3.94
24	3—0	4—4	3.26	3—3	4—7	3.48	3—6	4—10	3.70	3—8	5—0	3.85	4—0	5—4	4.15
25	3—0	4—5	3.43	3—3	4—8	3.66	3—6	4—11	3.90	3—8	5—1	4.05	4—0	5—5	4.36
26	3—0	4—6	3.61	3—3	4—9	3.85	3—6	5—0	4.09	3—8	5—2	4.25	4—0	5—6	4.57

In making estimates, due allowance should be made for the fact that trenches do not always conform to their theoretical dimensions. This

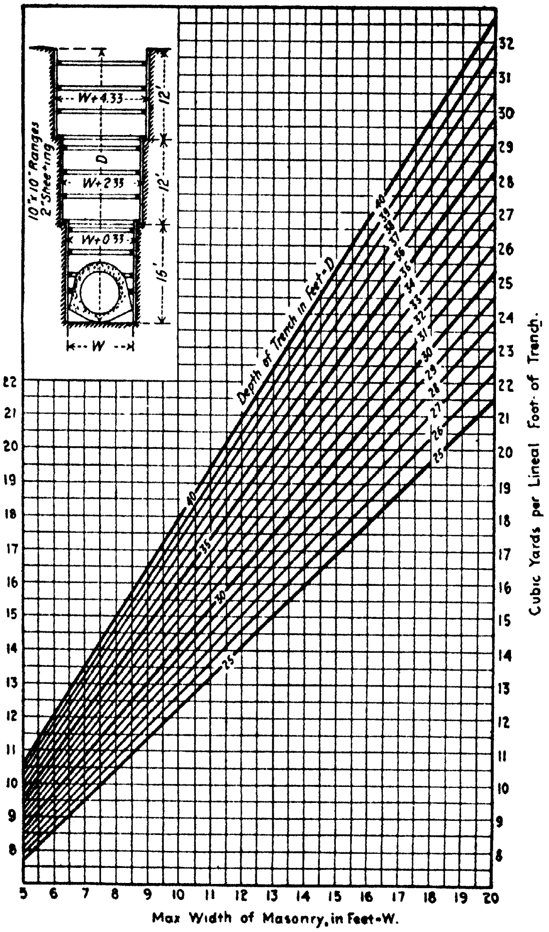


FIG. 53.—Theoretical quantity of excavation for trenches 25 to 40 ft. deep for sewers of 5 to 20 ft. outside diameter.

is well illustrated by comparing Figs. 53 and 54. Fig. 54 is based upon averages of actual measurements of cross-sections of about 25 trenches excavated in Louisville, Ky., under contracts for sewers costing about $2,400,000 and built between 1907 and 1912. It will be found by comparing these diagrams that the excess excavation in Louisville, for small sewers having an extreme outside width of 6 ft., was nearly 33 per cent., whereas the excess excavation for large sewers from 12 to 16 ft. outside diameter varied from 1 to 5 per cent., thus emphasizing the lessened importance of unnecessary width of trench upon very large work.

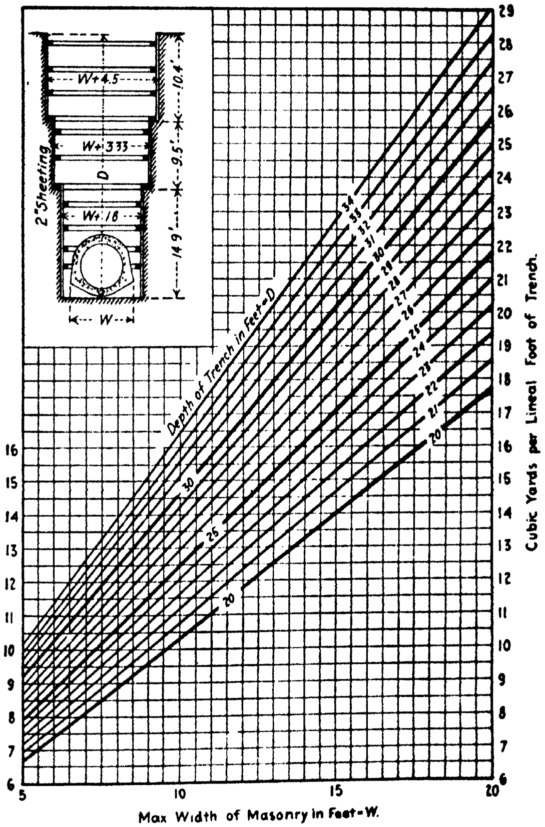


FIG. 54.—Average excavation in about 25 trenches, Louisville.

It should not be assumed from Fig. 54 that the trenches actually excavated were of such regular form as indicated by this drawing, which is based upon the average of a relatively large number of cross-sections, some of which corresponded closely with the theoretical cross-section, and others were very much wider and were ill-shaped, involving a large unnecessary quantity of excavation, as illustrated by numerous diagrams in Chapter IX, where experience with a variety of types of sheeting is recorded.

Measurement of Excavation.—The length of trench or sewer is usually measured from center to center of manholes on the surface of the ground parallel to the trench bottom or sewer.[1] The depths of excavation are determined from the record profile, being the difference between the elevations of the surface of the ground and the sewer. Sometimes it is specified that measurements shall be made to a point, such as 0.2 ft., below the pipe invert or pipe grade line.

Elevations of the surface should be taken at each grade board or at intervals of about 25 ft. The depth of the sewer as shown on the profile should be checked at each manhole. It is of convenience in making computations of volume to be able to compute the cross-sectional area of the trench at uniform intervals.

Elevations on the surface of rock should be taken before blasting at intervals of 5 or 10 ft., depending upon the character of the surface, and in the case of very jagged rock surfaces, at such other points as may be necessary to measure the rock accurately.

A section of trench may be considered as having the form of a "prismoid," that is, a solid having parallel end areas and composed of any combination of prisms, wedges or pyramids whose bases and apices lie in the end areas.

A sewer trench usually has similar parallel cross-sections and a uniform width. The volume of such a trench may be computed by the method of averaging end areas, the formula for which is as follows:

$$v = \frac{l}{2}(A_1 + A_2)$$

v = volume of section in cubic feet.

l = perpendicular distance between end cross-sections, in feet.

A_1 and A_2 = areas of end cross-sections in square feet.

In the case of trenches as just described, where sections are taken at regular intervals the computations may be combined in one formula as follows:

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[1] Extract from Standard Specifications for Construction of Main and Branch Sewers, Philadelphia: "The length of sewer built shall be reduced to and paid for in horizontal measure of City District standard feet. All vertical dimensions are given and are to be measured in the United States standard feet, and when preceded by the sign + or − respectively to above or below an established horizontal plane called City Datum, which is 2.25 ft. above mean high water and 7.59 ft. above mean low water in the Delaware River at Philadelphia. The length of sewer to be paid for will include the space taken up by manholes."

$$V = \frac{l}{27}\left(\frac{A_1}{2} + A_2 + A_3 + A_4 + A_5 + \ldots A_{n-1} + \frac{A_n}{2}\right)$$

V = volume of continuous line of earthwork in cubic yards as computed by averaging end areas.

l = perpendicular distance between cross-sections in feet.

n = number of cross-sections.

or

$$V = \frac{lw}{27}\left(\frac{d_1}{2} + d_2 + d_3 + d_4 + d_5 \ldots + d_{n-1} + \frac{d_n}{2}\right)$$

where w = uniform width of trench in feet.

d_1, d_2, d_3, d_n, etc. = depths of trench in feet at each cross-section taken at regular intervals.

In the case of sewer trenches which have dissimilar parallel cross-sections and non-uniform width, the approximate volume may be found by the method of averaging end areas as above, but a more accurate method is by the prismoidal formula as follows:

$$v = \frac{l}{6}(A_1 + 4A_m + A_2)$$

v = volume of section in cubic feet.

l = perpendicular distance between end cross-sections, in feet.

A_1, A_m, A_2 = the areas of end and middle cross-sections in square feet.

In measuring excavation or grading over extended areas, the ground should be staked out, or cross-sectioned, in equal rectangles or squares, not over 50 ft. on a side, of such size that the surfaces of the rectangles may be considered as planes. Elevations should be taken at the corner stakes. After the earthwork is completed, the ground should be re-staked on the same points as before and the final elevations at the corner stakes taken. The differences between these two sets of elevations will give the depths of excavation or fill at the corresponding corners. The volume of the excavation or fill may be computed by the following formula:

$$V = \frac{A}{4 \times 27}(\Sigma h_1 + 2\Sigma h_2 + 3\Sigma h_3 + 4\Sigma h_4).$$

V = volume of earthwork in cubic yards.

A = horizontal area of unit rectangle in square feet.

Σh_1 = summation of corner heights which have *one* rectangle adjoining. The subscripts denote the number of adjoining rectangles each of which has an area of A.

The approximate quantity of earthwork may also be calculated from the areas enclosed by contour lines, these areas being obtained most readily by the use of a planimeter. The volume is calculated by the prismoidal formula previously given, the prismoid being vertical in this case and lying between the contour planes.

There is often a considerable difference in the quantity of earthwork as computed by the average end area method and the prismoidal formula and as in several states the courts of final jurisdiction have decided that the prismoidal method, while the more accurate, is not the customary method of computing excavation, it is always well to state in the specifications the method which will be followed. In all questions of mensuration, courts usually follow local custom unless there is a specific agreement in the contract as to a method.

Thus far the computations of volume have been based on the assumption that the center line is straight with all cross-sections at right angles to it. If, however, the center line is on a curve, then the cross-sections will not be parallel to each other but will be radial. In the usual case, where the surface is level, the cross-section is symmetrical about the center line which passes through the center of gravity of the section. For this case, the prismoidal formula gives the correct result and no correction for curvature is necessary.

If the trench excavation is on a side hill slope so that the cross-section is unsymmetrical about the center line, a correction must be made to allow for the increase or decrease in volume depending on the location of the center of gravity of the cross-section, whether outside or inside the center-line curve.

For further discussion of this subject see "Field Engineering" by Searles and Ives, Vol. I, 17th Edit., p. 236.

COST OF EXCAVATION IN GENERAL

The attempt to give definite information concerning the cost of excavation is apt to be misleading on account of the great difference in the character of materials encountered, the location of the work, and the labor and machinery available. In order to give the student or the young engineer some conception of current prices prevailing in excavation work the following statement has been prepared, which is to be used only as a rough guide and not for specific application.

In ditching and building shallow canals in peaty or fibrous alluvium, which can readily be handled by machine, the cost has been found to be as low as 4 to 5 cents per cubic yard. The handling of such materials, together with some sandy material and sandy or alluvial deposit in river dredging, has often been done for 10 cents, more or less, per cubic yard where the material could be handled by suction or other type of dredge particularly suited to it.

In the case of the more compact and sticky materials dredging operations have generally cost from 20 to 30 cents per cubic yard in the harbors along the eastern coast of the United States.

In making dams and railroad fills by the hydraulic sluicing process, more particularly in the western parts of the United States, the cost is usually about 15 cents per cubic yard where the water is pumped and 7 to 10 cents where water can be diverted from a nearby creek, both including pipe line installation.

Excavation by steam shovel has generally ranged from 20 to 30 cents per cubic yard, depending upon the hardness of the material encountered; and in the case of shale or other rock which is not too hard to be readily shaken up by explosives so that it can be handled by steam shovels, upon heavy work prices of 75 cts. to $1 per cubic yard have not been uncommon. The cost of removing the spoil is often a very important element on steam shovel work.

Excavation by drag or wheel scraper may cost from 20 to 30 cents per cubic yard as against 25 to 40 cents if handled by hand and carts. Shallow trench excavation by hand is likely to cost 25 to 35 cents in easy soils, and in the harder work, 40 to 50 cents per cubic yard, more or less, and may reach considerably higher limits. If the excavation goes below the water table or ground water line, the cost will increase rapidly with the depth to which the excavation is carried, reaching in the case of quicksands, requiring special precaution for their handling, such as sheeting and bracing and pumping, prices from $2 to $3 per cubic yard.

In heavy trench excavation for large sewers, where steam shovels or orange-peel dredges can be used, the cost of excavation in favorable and reasonably dry materials, is likely to be approximately $1 per cubic yard, the cost increasing with the difficulties encountered, particularly the amount of water.

The cost of rock excavation also varies widely upon trench work. The shales of the Middle West can generally be handled at $1 to $2 per cubic yard, the harder conglomerates, granites and gneisses of the East at $4 to $5 per cubic yard, in shallow trenches, the cost of rock work increasing materially with the depth of the trench where the width of the trench is small.

In the case of tunnel work, the removal of the rock for the minimum bore, approximately two-thirds of a cubic yard per linear foot of tunnel, may be figured at from $15 per cubic yard more or less for igneous rocks to about $3 for sedimentary rocks, and the additional rock excavation involved in any desired section may then be figured at the smaller cost of enlarging the drift, in general from $6 per cubic yard more or less to perhaps $2 per cubic yard, depending upon the character of the rock, but the cost will vary substantially with the amount of work to be done, material encountered, labor and machinery available, accessibility, etc.

Cost of Louisville Sewerage Project.—The Commissioners of Sewerage of Louisville, Ky., kept an accurate and itemized record of the costs of the several contracts under which they built about 54 miles of sewers during the six years from 1907 to 1912. As such complete records upon so large a project are rarely available it is believed that they will prove of sufficient value for reference to warrant their publication. A portion of the data is taken from the final report of the Commissioners, dated March 31, 1913. The detailed costs, given in Tables 33, 34 and 35, have been computed by the authors from data taken from the original files.

A distribution of the main items of expense on contract work is given in Table 29. The total cost of this work is seen to have been over $3,700,000, of which 2.09 per cent. was for administration and 9 per cent. for engineering. All of the contracts, of which there were 86, were advertised, with one exception. Prior to the opening of bids upon each contract, the engineer prepared a preliminary estimate of the cost of the work included in the proposals and of the total cost of the work. A comparison of these estimates with the amounts of lowest proposals and amounts paid contractors may be made from the data given in Table 30. The Chief Engineer, J. B. F. Breed, made the following comment upon these estimates and bids:

TABLE 29.—DISTRIBUTION OF MAIN ITEMS OF EXPENSE, ON CONTRACT WORK, TO JANUARY 31, 1913

Item	Total cost	Percentage of total expenditures
Administration	$78,025 03	2 09
Engineering	336,544 87	9 00
Right of way	12,319 36	0 33
Castings and other metal work supplies	15,461.29	0 41
Damage suits (exclusive of rights of way)	8,307 52	0 22
Amount of payments to contractors	3,289,330 89	87 95
	$3,739,988 96	100 00

"While the bases of these estimates doubtless varied from time to time, depending on market conditions, price of labor, and the tendency of contractors to bid higher or lower than previously, it is believed that these variations have not been large. Diagram 55 shows graphically the relation between the Engineer's estimates and the lowest bids received. It will be noticed that during 1907, 1908 and the first six months in 1909, the proposals were almost invariably below the Engineer's estimate. During the latter part of 1909, there was a decided tendency toward an increase in contract prices with reference to the Engineer's estimates and in 1910 and 1911, the prices were materially higher than the estimates. This decided tendency toward higher prices led to the decision to do some of the work by day labor in cases where the tenders were materially in excess of the Engineer's estimate." (1913 Rpt., p. 42.)

Work upon the first sewer to be built by day labor was begun in the summer of 1910 after which time the Commission seriously considered doing by day labor any work covered by proposals which exceeded the engineer's estimate by substantially more than 10 per cent. This policy apparently had an effect in reducing somewhat the prices bid.

The current prices of labor increased considerably during the time

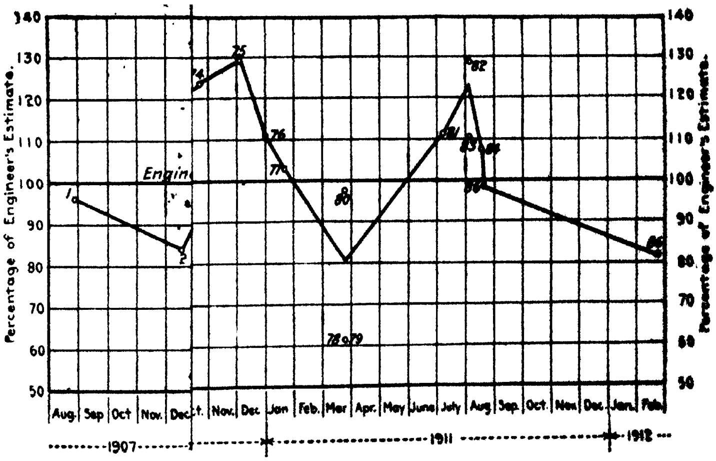

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TABLE 30.—ENGINEER'S ESTIMATES, PROPOSALS AND COST OF COMPLETED CONTRACTS, LOUISVILLE

Contract number	Amount of lowest proposal	Engineer's preliminary estimate of cost of work included in proposal	Amount paid contractor	Engineer's preliminary estimate of total cost	Total cost of completed sewer
1	$ 25,641.02	$27,650.00	$ 28,882.60	$ 30,279.89	$ 31,035.09
2	296,524.13	353,145.00	296,296.52	351,261.61	330,167.78
3	3,974.50	4,138.72	4,068 52	4,654 89	4,366.01
4	91,698.98	121,529.00	97,731.12	110,535.97	109,650.47
5	215,913.50	280,074.00	219,087 50	257,309.97	250,438.12
6	91,597.64	134,782.90	101,543.17	112,489.01	118,949.34
7	16,443.26	21,773 20	17,615.56	19,818.11	22,995.01
8	30,035.54	36,299.60	28,315.20	35,661.98	34,331.12
9	25,275 82	31,032 59	24,446.80	30,085 87	30,408.97
10	6,956.05	6,873 68	8,120 93	8,021.47	9,692.37
11	185,470.38	245,491 95	139,227 68	223,382 13	165,133.43
12	7,058.86	7,813.57	7,688 85	8,269 97	9,372.39
13	12,009 71	15,292 81	13,133.22	14,380.09	15,604.08
14	106,471 52	122,949.53	107,742 81	125,528 69	127,269.43
15	8,984.89	11,299.79	9,520 10	10,736.36	10,794.16
16	35,124.15	38,355.80	32,656.68	41,069 30	36,383.29
17	18,352 46	18,540.28	20,078 82	22,438.50	22,185.39
18	27,251.76	30,179.34	27,083 24	31,928 56	29,310.93
19	12,246.34	11,860.34	15,525 64	14,084.69	17,686.35
20	70,554 28	92,511.96	71,865.61	84,893.64	80,168.05
21	1,746 83	2,731.24	2,804.89	2,170 17	3,278.00
22	6,350.94	10,895.68	7,474 24	8,039 77	8,671.52
23	2,347.66	2,752.14	4,130 96	2,774 23	4,510.66
24	2,781.90	4,183.70	4,490.27	3,430.37	5,744.33
25	79,156.20	117,879 26	81,121.93	97,427 49	95,647.82
26	16,035.76	17,922 07	13,544.37	18,813 68	15,846.77
27	12,148 55	14,672 54	15,567.61	15,439.18	17,902.05
28	37,784 10	40,746.60	46,851 54	44,099.82	53,515.10
29	85,428.98	106,771.93	85,032 20	101,978.63	96,760.33
30	19,133.01	21,421.53	21,303.48	22,453.35	24,224.91
31	12,658.43	11,511.92	11,511.40	14,442.72	14,162.67
32	10,086 63	10,549.59	9,265.16	11,721.82	10,959.40
33	8,136.70	8,898.70	8,641.63	9,515 99	9,906.86
34	2,674 47	3,316 68	3,688 64	3,188.55	4,014.08
35	30,670 30	38,925 93	32,601.16	36,703 82	39,953.34
36	137,525.04	156,538.47	137,984.23	161,787 26	162,845.43
37	4,828 34	6,150.82	6,401 77	5,781.72	7,136.79
38	1,992.18	2,660.91	2,531 82	2,404.62	2,758.89
39	2,176.37	3,322.02	2,655 83	2,691.28	2,897.46
40	5,967.66	6,616.60	5,765.71	6,376.48	6,523.08
41	69,575.88	64,638.00	80,210.82	79,594.77	85,025.13
43	27,385.68	25,860.86	26,996.03	31,394.12	30,991.92
44	47,744.22	50,545.79	36,372.60	55,578.82	43,531.45

Table 30.—Engineers' Estimates, Proposals and Cost of Completed Contracts, Louisville.—(*Continued*)

Contract number	Amount of lowest proposal	Engineer's preliminary estimate of cost of work included in proposal	Amount paid contractor	Engineer's preliminary estimate of total cost	Total cost of completed sewer
45	78,011.00	96,841.20	94,027.16	93,021.39	101,682.01
46	12,809.51	11,217.21	15,502.22	14,548.18	16,831.77
47	4,588.69	7,690 99	5,104.40	5,780.79	5,619.77
48	51,484.65	47,016 70	51,298.78	58,772.23	57,940.96
49	43,965.45	37,711 00	43,525.36	49,810.66	52,698.59
50	20,071 88	22,189.29	17,669.03	23,511.23	20,859.24
51	87,055.23	94,682.36	90,066.93	101,731.00	99,082.19
52	11,984.51	11,221 19	10,538.16	13,723.80	12,094.94
53	144,557.75	151,369.98	135,059.87	168,020.10	149,096.15
54	80,064 72	80,980 68	79,622 38	92,616.72	84,565.04
55	79,504.80	76,695 36	75,008.33	91,392.50	85,434.31
56	(44,062.61)	56,259.94	41,204.29	(50,251.20)	43,974.22
57	5,095.10	5,850.40	5,608 06	6,001.91	6,626.74
58	32,355 08	28,268 58	32,280 86	36,736.71	35,850.56
59	30,113.40	28,227.67	32,146.57	34,488.63	35,955.76
60	34,226.22	30,203 38	−[1]4,568.73	(38,907.74)	− 1,347 69
61	54,040 39	40,719.63	56,076.66	60,351.93	61,763.05
62	102,643.37	143,922.18	118,868.79	124,951.31	129,776.04
63	23,432.52	21,029.20	24,213.94	26,692.05	26,613.58
64	44,251.00	36,101.29	48,736.06	49,846 71	52,217 59
65	15,998 45	14,693.25	15,978.06	18,275.90	18,533.75
66	25,559 83	18,438 66	27,633.17	28,417.82	30,170.46
67	29,259 80	23,087.40	30,440.74	32,838.35	34,561.36
68	4,284.30	4,886.56	4,517.44	5,041.72	4,879.32
69	19,572 48	15,073.16	22,788.53	21,908.82	27,328.02
70	9,865 79	12,078 10	11,116.78	11,737.89	13,027.02
72	45,225 56	40,807.15	44,374.48	51,550.67	50,919.18
73	51,413.30	....	57,299.99	56,094.82	59,508.57
74	18,787.70	15,183.15	20,389.23	21,141.09	22,069.02
76	21,337.00	19,189.15	20,236.32	24,311.32	23,867.61
77	31,161.30	31,048.14	34,174.06	35,973.76	39,203.74
78	2,307.60	3,779.70	2,779.30	2,893.45	3,212.90
79	3,510.43	5,765.86	4,192.88	4,404.15	4,840.90
80	10,559.20	10,836.95	10,793.94	12,238.92	14,153.40
81	18,892.57	16,986.94	19,263.38	21,525.54	26,948.37
83	7,479.89	6,763.48	8,055.62	8,528.23	9,111.29
84	29,340.03	27,243.00	28,191.79	33,562 69	33,747.00
85	23,126.31	23,498.52	22,684.30	26,768.58	27,001.32
86	13,580.17	16,716.77	14,852.90	16,171.27	17,642.07
Total	$3,233,437.60	... ...	$3,289,330.89	$3,767,104.60	$3,740,869.69

[1] $8,480.00 recovered from contractor for failure to complete work. Figures in parentheses not included in total.

the Commission was doing its work. The minimum price paid for common labor in 1907 and 1908 was $1.35 per day, while during the last three years it is doubtful if any material amount of labor was obtained for less than $1.75, and in many cases a rate as high as $2 per day was paid. It does not appear that the prices of materials varied as much as the price of labor, although there was a tendency toward an increase in price during the period covered by the work.

A comparison of the cost of four sewers built by day labor with the amounts of the lowest proposals can be made from the data given in Table 31. These data appear to indicate that the Commissioners made a material saving by doing this work by direct labor. It should be remembered, however, that the proposals for this work were materially higher than the Engineer's preliminary estimates. It should not be inferred that there would have been a similar saving or, in fact, any economy had the Commissioners undertaken to do all of the work by direct labor.

In Louisville, as in many other cities, there was some criticism, perhaps due in part to local pride, because the work was not awarded in all cases to local contractors. The Commissioners adopted the policy of advertising the contracts, which resulted in 445 bids from 72 contractors, only 26 of whom were residents of Louisville. On every contract there were several bids, and in every instance either the award was made to the lowest bidder, or, if the lowest proposal was deemed by the Commissioners to be too high, the work was done by direct labor. The lowest local bids

TABLE 31.—ENGINEER'S ESTIMATES, PROPOSALS AND COST OF WORK DONE BY DAY LABOR, LOUISVILLE, KY.

Number	Name of sewer	Amount of lowest proposal	Engineer's preliminary estimate of cost of work included in proposal	Cost of work done under items included in proposal		Engineer's preliminary estimate of total cost of work	Administration, engineering, rights of way, incidentals	Total cost of completed work
				Calculated at prices in proposal	Actual cost by day labor			
42	Sec. A—Northwestern sewer...	$58,433 35	$42,489.22	$58,433.35	$41,681.46	$49,075.05	$6,329.25	$48,010.71
71	Sec. B—Oak Street.......	36.771.06	27,143.48	37,955.84	30,435 70	31,350 72	2,772 66	33,208.36
75	Eighth and St. Catherine Sts...	44,404.20	34,357.16	45,144 51	30,764.33	39,682.52	9,905.54	40,669.87
82	Sec. D—Middle Fork sewer....	19,329.85	15,033.47	19,935.75	18,804.41	17,363.66	7,040.90	25,845.31
				$161,469.45	$121,685.90			$147,734.25

upon 22 of the larger contracts aggregated over $575,000 more than the lowest bids, indicating what it would have cost the city to have awarded the contracts in all cases to local bidders. An analysis of the cost of the sewers built by contract is given in Table 33, from which can be ascertained the amounts paid to the contractor for extra work, the bonus for completing the work ahead of the contract time, and payments on account of claims. This table also shows the amounts collected from the contractors as liquidated damages on account of delay in completing the work within the time specified.

An analysis of the cost of building the Louisville sewers has been made by the authors, the data thus obtained being included in Tables 34 and 35. In presenting these data, an effort has been made to give to the reader some idea of the nature of the excavation encountered, the amount and character of pavement taken up and replaced and the quantity of rock excavated. The contracts provided for the payment for earth excavation at the price bid per linear foot of sewer constructed. These prices have been reduced to price per cubic yard of excavation, which in turn has been computed for an assumed trench included between vertical planes 6 in. on each side outside the extreme limits of required masonry section. In studying the costs given in these tables, the reader should bear in mind that a very large proportion of the sewers was built in material easily excavated and that water, in amounts requiring pumping, and quicksand were encountered in only very few instances. For information regarding methods of excavation and machinery used, reference may be had to Table 37.

Upon these Louisville contracts, the linear foot price was paid, regardless of the presence of rock. The computation of the units in the last two columns of Table 34 was based on the entire cross-section of the trench. Where rock was encountered the prices given in Table 34 were paid in addition to the linear-foot prices. Where no prices are given in the columns relating to Pavement, Concrete Base and Rock, none of the work was done. In studying Table 35, it should be borne in mind that on nearly all of the Louisville work, the concrete was mixed in the proportions of one part of cement to seven parts of aggregate composed of sand and river gravel mixed in proportions directed on the work. The reinforcement was mild steel, plain or deformed bars, the latter being used in most cases.

Cost of Excavation and Backfilling, Denver, Col.—In some localities in the middle and western portions of the country, the conditions in suburban districts are remarkably favorable to inexpensive excavation. The soil is of such a nature that comparatively little sheeting and bracing are required, there are few subsurface structures crossing the streets, and traffic conditions place little restriction upon the use of the streets by sewer builders.

TABLE 32.—ACTUAL COST TO CONTRACTOR OF EXCAVATION AND BACKFILLING, DENVER, COLO.

(Overhead Charges and Profit are Assumed)

Item	Machine work	Hand work	Sub-contract	Total
Linear feet..	65,902	10,005	36,093	112,000
Cubic yards	54,347	5,591	26,080	86,017
Depth cut, ft	8.9	6.8	9.7	9.1
Width, ft	2.5	2.0	2.0	2.29
	Cents per cu yd	Cents per cu yd	Cents per cu yd.	Cents per cu. yd.
Machine working	2.21			
Machine idle	2.78			
Hand trenching	1.79	25.99	26.62	18.74
Backfilling.	3.62	4.29	4.07	3.80
Cleaning up.. .	0.45	0.54	0.77	0.55
Sheeting....	0.04		0.03	0.03
General service	2.03	5.60	0.77	1.89
Equipment (labor expense)	0.26	0.71	0.09	0.23
Material (labor expense)	0.32	0.90	0.12	0.30
Machine (labor expense)	0.55			
Repairs	3.03			
Oil	0.32			
Coal..........	1.84			
Equipment.	0.13	0.39	0.34	0.22
General expense	0.08	0.21	0.20	0.12
Team expense	0.42	0.63	0.09	0.16
Machine expense .	1.42			
Repairs upon machine after completion	8.30			5.20
Sub-total.	29.59	39.36	33.10	31.24
Overhead expenses, 10 per-cent....	2.96	3.94	3.31	3.12
Sub-total	32.55	43.30	36.41	34.36
Profit, 15 per cent	4.88	6.50	5.46	5.15
Grand total. ...	37.43	49.80	41.87	39.51

Note.—Machine constantly employed for about 8 months. Average rate of progress of machine, 320 ft. per day; maximum, about 1000 ft. per day, followed by 3-1/2 days out of commission for repairs.

Data furnished through the courtesy of James Collier, of the National Concrete Construction Co., upon the actual cost to the company of earthwork incident to the construction of 112,000 ft. of 8-in. sewer in Denver, illustrate the low cost of such work done under favorable conditions and the advantage of the use of excavating machines of the digging type. The contract with the city covered the building of a sanitary sewer in sub-district 8. Construction covered 10 months, beginning with the fall of 1908. The material excavated was all dry, hard clay; no sheeting was required. Labor cost $2 per day of 9 hours, or 22-1/2 cents per hour. A part of the work was done with the aid of a 28-in. by 12-ft. Buckeye traction digger costing $8000 at Findlay, Ohio, plus freight and expenses of $2000. Another portion was done by hand, while a third portion was sublet. The quantities and unit costs of work done in these three ways, and the totals, are given in Table 32. To the actual costs should be added overhead expenses, here estimated at 10 per cent. and a reasonable profit, which, for the sake of arriving at a total, has been assumed at 15 per cent.

TABLE 33.—ANALYSIS OF COST OF SEWERS BUILT BY CONTRACT AT LOUISVILLE, KY., 1907–1912

Contract Number	Payment to Contractor						Liquidated Damages Charged to Contractor		Payment to Contractor on Account of Claims for Damages		Total Payment to Contractor		Engineering Administration and Incidentals		Total Cost of Sewer	
	At Contract Price		For Extra Work		For Bonus											
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
1	27,922.70	96.68 89.97	1,209.90	4.19 3.90			500.00	1.73 1.61	250.00	0.86 0.80	28,882.60	100.00 93.06	2,152.49	6.94	31,035.09	100.00
2	299,114.70	100.95 90.59	431.82	0.14 0.13			3,250.00	1.09 0.98			296,296.52	100.00 89.74	33,871.26	10.26	330,167.78	100.00
3	4,059.18	99.77 92.97	9.34	0.23 0.21							4,068.52	100.00 93.19	297.49	6.81	4,366.01	100.00
4	96,296.28	98.53 87.82	1,434.84	1.47 1.31							97,731.12	100.00 89.13	11,919.35	10.87	109,650.47	100.00
5	218,359.73	99.67 87.19	3,302.77	1.50 1.32			2,575.00	1.17 1.02			219,087.50	100.00 87.49	31,350.62	12.51	250,438.12	100.00
6	93,768.80	92.34 78.83	9,274.37	9.13 7.80			1,500.00	1.47 1.26			101,543.17	100.00 85.37	17,406.17	14.63	118,949.34	100.00
7	16,759.75	95.14 72.88	230.81	1.31 1.00	625.00	3.55 2.72					17,615.56	100.00 76.61	5,379.45	23.39	22,995.01	100.00
8	29,877.90	105.52 87.03	37.30	0.13 0.11			1,600.00	5.65 4.66			28,315.20	100.00 82.48	6,015.92	17.52	34,331.12	100.00
9	25,621.80	104.80 84.26					1425.00	5.82 4.68	250.00	1.02 0.82	24,446.80	100.00 80.40	5,962.17	19.60	30,408.97	100.00
10	7,749.37	95.43 79.95	71.56	0.88 0.74					300.00	3.69 3.10	8,120.93	100.00 83.79	1,571.44	16.21	9,692.37	100.00
11	140,173.53	100.68 84.89	2,704.15	1.94 1.64			3,650.00	2.62 2.21			139,227.68	100.00 84.32	25,805.75	15.63	165,133.43	100.00
12	7,019.81	91.30 74.90	169.04	2.20 1.80	500.00	6.50 5.33					7,688.85	100.00 82.04	1,683.54	17.96	9,372.39	100.00
13	12,855.04	97.88 82.38	278.18	2.12 1.78							13,133.22	100.00 84.16	2,470.86	15.84	15,604.08	100.00
14	108,870.18	101.05 85.54	272.63	0.25 0.21			4,400.00	4.08 3.46	3,000.00	2.78 2.36	107,742.81	100.00 84.66	19,526.62	15.34	127,269.43	100.00
15	9,035.80	94.91 83.71	59.30	0.62 0.55	425.00	4.46 3.94					9,520.10	100.00 88.20	1,274.06	11.80	10,794.16	100.00
16	33,756.68	103.37 92.78					1,100.00	3.37 3.02			32,656.68	100.00 89.76	3,726.61	10.24	36,383.29	100.00
17	19,864.47	98.93 89.54	214.35	1.07 0.96							20,078.82	100.00 90.50	2,106.57	9.50	22,185.39	100.00
18	27,648.87	102.09 94.33	34.37	0.12 0.12			600.00	2.21 2.04			27,083.24	100.00 92.40	2,227.69	7.60	29,310.93	100.00
19	15,560.66	100.23 87.98	289.98	1.87 1.63			325.00	2.09 1.83			15,525.64	100.00 87.78	2,160.71	12.22	17,686.35	100.00
20	71,781.04	99.88 89.54	334.57	0.46 0.42			250.00	0.34 0.31			71,865.61	100.00 89.64	8,302.44	10.36	80,168.05	100.00
21	1,746.49	62.27 53.28	8.40	0.30 0.26	1,050.00	37.44 32.03					2,804.89	100.00 85.57	473.11	14.43	3,278.00	100.00
22	6,453.02	86.34 74.42	21.22	0.28 0.24	1,000.00	13.38 11.53					7,474.24	100.00 86.19	1,197.28	13.81	8,671.52	100.00

All amounts are given in dollars.

TABLE 33.—ANALYSIS OF COST OF SEWERS BUILT BY CONTRACT AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Payment to Contractor						Liquidated Damages Charged to Contractor		Payment to Contractor on Account of Claims for Damages		Total Payment to Contractor		Engineering Administration and Incidentals		Total Cost of Sewer	
	At Contract Price		For Extra Work		For Bonus											
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
23	2,305.96	55.82 51.12			1,825.00	44.18 40.46					4,130.96	100.00 91.58	379.70	8.42	4,510.66	100.00
24	2,905.25	64.70 50.58	10.02	0.22 0.17	1,575.00	35.08 27.42					4,490.27	100.00 78.17	1,254.06	21.83	5,744.33	100.00
25	82,741.46	102.00 86.51	1,580.47	1.95 1.65			5,350.00	6.60 5.59	2,150.00	2.65 2.25	81,121.93	100.00 84.82	14,525.89	15.18	95,647.82	100.00
26	15,519.37	114.58 97.93					2,475.00	18.27 15.62	500.00	3.69 3.16	13,544.37	100.00 85.47	2,302.40	14.53	15,846.77	100.00
27	14,684.35	94.33 82.03	158.26	1.02 0.88	725.00	4.65 4.05					15,567.61	100.00 86.96	2,334.44	13.04	17,902.05	100.00
28	45,480.94	97.07 84.99	1,195.60	2.55 2.23	175.00	0.38 0.33					46,851.54	100.00 87.55	6,663.56	12.45	53,515.10	100.00
29	83,889.58	98.65 86.69	492.62	0.58 0.51			1,150.00	1.35 1.18	1,800.00	2.12 1.86	85,032.20	100.00 87.88	11,728.13	12.12	96,760.33	100.00
30	21,858.09	102.61 90.22	45.39	0.21 0.19			600.00	2.82 2.47			21,303.48	100.00 87.94	2,921.43	12.06	24,224.91	100.00
31	12,581.40	109.30 88.84	5.00	0.04 0.03			1,075.00	9.34 7.59			11,511.40	100.00 81.28	2,651.27	18.72	14,162.67	100.00
32	10,707.10	115.56 97.69	258.06	2.78 2.36			1,700.00	18.34 15.51			9,265.16	100.00 84.54	1,694.24	15.46	10,959.40	100.00
33	9,053.32	104.77 91.39	13.31	0.16 0.13			675.00	7.82 6.81	250.00	2.90 2.52	8,641.63	100.00 87.23	1,265.23	12.77	9,906.86	100.00
34	2,563.64	69.50 63.86			1,125.00	30.50 28.03					3,688.64	100.00 91.89	325.44	8.11	4,014.08	100.00
35	34,742.92	106.57 86.95	458.24	1.40 1.15			2,600.00	7.97 6.50			32,601.16	100.00 81.60	7,352.18	18.40	39,953.34	100.00
36	136,472.13	98.90 83.80	1,512.10	1.10 0.93			1,900.00	1.38 1.17	1,900.00	1.38 1.17	137,984.23	100.00 84.73	24,861.20	15.27	162,845.43	100.00
37	5,414.18	84.57 75.86	687.59	10.74 9.64	300.00	4.69 4.20					6,401.77	100.00 89.70	735.02	10.30	7,136.79	100.00
38	1,956.82	77.29 70.93			575.00	22.71 20.83					2,531.82	100.00 91.76	227.07	8.24	2,758.89	100.00
39	2,144.96	80.77 74.03	10.87	0.40 0.37	500.00	18.83 17.26					2,655.83	100.00 91.66	241.63	8.34	2,897.46	100.00
40	5,706.53	98.97 87.48	9.18	0.16 0.14	50.00	0.87 0.77					5,765.71	100.00 88.39	757.37	11.61	6,523.08	100.00
41	80,008.15	99.74 94.10	327.67	0.41 0.38			125.00	0.15 0.14			80,210.82	100.00 94.34	4,814.31	5.66	85,025.13	100.00
43	28,313.80	104.88 91.36	957.23	3.55 3.09			2,275.00	8.43 7.34			26,996.03	100.00 87.11	3,995.89	12.89	30,981.92	100.00
44	37,913.85	104.24 87.10	8.75	0.02 0.02			1,550.00	4.26 3.56			36,372.60	100.00 83.56	7,158.85	16.44	43,531.45	100.00
45	95,047.59	101.08 93.48	279.57	0.30 0.27			1,300.00	1.38 1.27			94,027.16	100.00 92.48	7,654.85	7.52	101,682.01	100.00

TABLE 33.—ANALYSIS OF COST OF SEWERS BUILT BY CONTRACT AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Payment to Contractor						Liquidated Damages Charged to Contractor		Payment to Contractor on Account of Claims for Damages		Total Payment to Contractor		Engineering Administration and Incidentals		Total Cost of Sewer	
	At Contract Price		For Extra Work		For Bonus											
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
46	14,123.55	91.11 83.91	628.67	4.05 3.74	750.00	4.84 4.45					15,502.22	100.00 92.10	1,329.55	7.90	16,831.77	100.00
47	4,549.83	89.13 80.96	29.57	0.58 0.52	525.00	10.29 9.35					5,104.40	100.00 90.83	515.37	9.17	5,619.77	100.00
48	54,473.78	106.19 94.02					4,225.00	8.24 7.29	1,050.00	2.05 1.81	51,298.78	100.00 88.54	6,642.18	11.46	57,940.96	100.00
49	44,485.09	102.20 84.41	165.27	0.38 0.31			1,125.00	2.58 2.13			43,525.36	100.00 82.59	9,173.23	17.41	52,698.59	100.00
50	19,016.99	107.63 91.17	102.04	0.58 0.49			1,450.00	8.21 6.95			17,669.03	100.00 84.71	3,190.21	15.29	20,859.24	100.00
51	89,698.91	99.59 90.53	368.02	0.41 0.37							90,066.93	100.00 90.90	9,015.26	9.10	99,082.19	100.00
52	11,991.82	113.79 99.15	21.34	0.20 [illegible]			1,475.00	13.99 12.19			10,538.16	100.00 87.13	1,556.78	12.87	12,094.94	100.00
53	135,709.87	100.48 91.02	75.00	0.05 0.05			3,725.00	2.75 2.50	3,000.00	2.22 2.01	135,059.87	100.00 90.58	14,036.28	9.42	149,096.15	100.00
54	79,897.38	100.34 94.48					275.00	0.34 0.32			79,622.38	100.00 94.16	4,942.66	5.84	84,565.04	100.00
55	80,058.33	106.73 93.71	--				5,050.00	6.73 5.91			75,008.33	100.00 87.80	10,425.98	12.20	85,434.31	100.00
56	44,604.29	108.25 101.41					3,400.00	8.25 7.62			41,204.29	100.00 93.79	2,769.93	6.21	43,974.22	100.00
57	5,108.06	91.09 77.08			500.00	8.91 7.55					5,608.06	100.00 84.63	1,018.68	15.37	6,626.74	100.00
58	32,864.85	101.81 91.66	91.01	0.28 0.25			675.00	2.09 1.88			32,280.86	100.00 90.04	3,569.70	9.96	35,850.56	100.00
59	31,833.07	99.02 88.54	313.50	0.98 0.87							32,146.57	100.00 89.41	3,809.19	10.59	35,955.76	100.00
60	3,911.27								-8480.00		-4,568.73	100.00	3,221.04		1,347.69	100.00
61	54,761.53	97.65 88.39	229.13	0.41 0.37	1,100.00	1.96 1.79	14.00	0.02 0.02			56,076.66	100.00 90.73	5,686.39	9.27	61,763.05	100.00
62	116,905.85	98.34 90.08	462.94	0.39 0.36	1,500.00	1.27 1.15					118,868.79	100.00 91.59	10,907.25	8.41	129,776.04	100.00
63	24,315.93	100.42 91.37	48.01	0.20 0.18			150.00	0.62 0.56			24,213.94	100.00 90.99	2,399.64	9.01	26,613.58	100.00
64	47,741.18	97.97 91.43	169.88	0.34 0.33	825.00	1.69 1.57					48,736.06	100.00 93.33	3,481.33	6.67	52,217.39	100.00
65	16,529.49	103.45 89.13	48.57	0.30 0.26			600.00	3.75 3.24			15,978.06	100.00 86.21	2,555.69	13.79	18,533.75	100.00
66	27,383.17	99.10 90.75			250.00	0.90 0.83					27,633.17	100.00 91.58	2,537.29	8.42	30,170.46	100.00
67	29,891.14	[illegible] [illegible]	174.60	0.57 0.51	375.00	1.23 1.09					30,440.74	100.00 88.07	4,120.62	11.93	34,561.36	100.00

TABLE 33.—ANALYSIS OF COST OF SEWERS BUILT BY CONTRACT AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Payment to Contractor						Liquidated Damages Charged to Contractor		Payment to Contractor on Account of Claims for Damages		Total Payment to Contractor		Engineering Administration and Incidentals		Total Cost of Sewer	
	At Contract Price		For Extra Work		For Bonus											
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
68	3,892.44	86.17 79.77			625.00	13.83 12.81					4,517.44	100.00 92.58	361.88	7.42	4,879.32	100.00
69	21,735.47	95.38 79.53	228.06	1.00 0.84	825.00	3.62 3.02					22,788.53	100.00 83.39	4,539.49	16.61	27,328.02	100.00
70	11,049.38	99.40 84.82	67.40	0.60 0.52							11,116.78	100.00 85.34	1,910.24	14.66	13,027.02	100.00
72	44,234.97	99.69 86.87	14.51	0.03 0.02	125.00	0.28 0.24					44,374.48	100.00 87.13	6,544.70	12.87	50,919.18	100.00
73	53,847.01	93.98 90.40	377.98	0.66 0.63	3,075.00	5.36 5.16					57,299.99	100.00 96.19	2,268.58	3.81	59,568.57	100.00
74	19,139.23	93.87 86.71			1,250.00	6.13 5.66					20,389.23	100.00 92.37	1,679.79	7.63	22,069.02	100.00
76	20,236.32	100.00 84.79									20,236.32	100.00 84.79	3,631.29	15.21	23,867.61	100.00
77	32,417.62	94.86 82.69	181.44	0.53 0.46	1,575.00	4.61 4.02					34,174.06	100.00 87.17	5,029.68	12.83	39,203.74	100.00
78	2,039.98	73.40 63.49	39.32	1.41 1.22	700.00	25.19 21.79					2,779.30	100.00 86.50	433.60	13.50	3,212.90	100.00
79	3,307.07	78.87 68.32	10.81	0.26 0.22	875.00	20.87 18.08					4,192.88	100.00 86.62	648.02	13.38	4,840.90	100.00
80	10,625.11	98.43 75.07	93.83	0.87 0.66	75.00	0.70 0.53					10,793.94	100.00 76.26	3,359.46	23.74	14,153.40	100.00
81	19,263.38	100.00 71.48									19,263.38	100.00 71.48	7,684.99	28.52	26,948.37	100.00
83	7,330.62	91.00 80.46			725.00	9.00 7.96					8,055.62	100.00 88.42	1,055.67	11.58	9,111.29	100.00
84	27,577.01	97.82 81.72	14.78	0.05 0.04	600.00	2.13 1.78					28,191.79	100.00 83.54	5,555.21	16.46	33,747.00	100.00
85	22,432.61	98.89 83.08	76.69	0.34 0.28	175.00	0.77 0.65					22,684.30	100.00 84.01	4,317.02	15.99	27,001.32	100.00
86	15,352.90	103.36 87.03					500.00	3.36 2.84			14,852.90	100.00 84.19	2,789.17	15.81	17,642.07	100.00
	3,290,643.69	100.04 87.96	32,431.20	0.98 0.87	26,900.00	0.82 0.72	66,614.00	2.02 1.78	5,970.00	0.18 0.16	3,289,330.89	100.00 87.93	451,538.80	12.07	3,740,869.69	100.00

Notes:

Extra Work Figured on Basis of Cost plus 15%.

Bonus for Completing Work Previous to Contract Limit or Liquidated Damages for Failure to so Complete Figured @ $25.00 per Day.

Percentages given, thus: $\frac{96.68}{89.97}$ Refer respectively to Payments to Contractor and to Total Cost of Sewer (including Engineering, Administration and Incidentals.

Contracts 1, 2 and 4 Contained the Liquidated Damage but not the Bonus Clause. Both Clauses were Omitted from Contracts 76 and 81.

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.*

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds)	Cost of Rock per Cu. yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
2	15'2" × 15'6" 14'5" × 15'0" 13'11" × 14'3"	3,337 1,841 965	29 9 34 6	Loam, Clay, Sand and Gravel						1,350 lin ft @ $14.20 950 " " " "17.20 1,043 " " " "14.50	22.5	$ 0.67
										1,100 " " " "16.60 1,700 " " " "16.00	26.5	0.61
5	13'8" × 14'0"	4,206	39 3	Clay, Sand and Gravel						825 " " " "25 00 1,979 " " " "25.00 1,402 " " " "25.00	26.5	0.94
11	13'6" × 13'9" 13'3" × 13'6" 12'11" × 13'3"	769 2,685 1,037	33.3	Clay, Sand and Gravel	Macadam	400				1,863 " " " "19.00 1,591 " " " "12 75 2,349 " " " "14 30	20.8	0.74
56	12'9" × 13'0"	1,326	34.2	Clay, Sand and Gravel						1,327 " " " "15.84	21.1	0.75
14	12'3" × 12'3" 12'0" × 12'0"	2,036 1,338	34 8	Clay, Sand and Gravel	Brick Macadam	508 390	6"			2,036 " " " "18.49 1,338 " " " "16.20	20.2	0.87
20	12'0" × 12'0"	2,438	34 9	Loam, Clay, Sand and Gravel	Brick	225	6"			2,440 " " " "15.20	20.2	0.75
6	8'0" × 8'0" 9'0" × 8'0" 10'1½" × 10'7"	48 93 1,897	41.5	Loam, Clay, Sand, Gravel and Rock						1,867 " " " "20.25	22.3	0.91

* See page 166 for comment on this table.

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu. yds.)	Cost of Rock per Cu. yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
45	10'0" × 10'0"	3,530	26.8	Clay, Sand and Gravel						3,530 lin ft @ $10.00	14.5	0.69
53	6'0" × 6'8" 9'0" × 13'6"	106 3,558	23 9	Loam, Clay, Sand, Gravel and Rock				1,000	4.00	1,420 " " " 24.75 2,244 " " " 11.50	16.9	0.98
54	9'0" × 12'0" 9'0" × 9'6" 9'0" × 9'0"	1,126 767 830	22.4	Loam, Clay, Sand, Gravel and Rock				10	3.50	2,723 " " " 13.85	12.2	1.13
51	9'6" × 9'6" 5'6" × 5'6"	1,837 3,051	26.1 169	Cinder, Sand, Gravel and Clay	Brick	331	6"	5	8 00	1,837 " " " 12.50 3,051 " " " 6.75	11.9 5.0	1.05 1.35
29	10'0" × 10'0" 7'8" × 7'8" 7'0" × 7'0"	115 1,997 1,951	24.8	Clay, Sand and Gravel	Brick Asphalt	1,100 100	6" 6"			115 " " " 18.36 1,997 " " " 11.88 1,951 " " " 9.72	10.5	1.03
62	7'6" × 10'0" 12"	5,200 60	16.6	Sand, Gravel, Clay and Fill				5	8 00	960 " " " 9.00 2,443 " " " 7.10 773 " " " 7.45 1,024 " " " 6.00 60 " " " 3.00	8.4	0.86
55	8'3" × 8'3"	1,727	20.5	Loam, Clay, Sand and Gravel						1,727 " " " 8.00	8.5	0.94

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907-1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu. yds)	Cost of Rock per Cu. yd (Dollars)	Cost of Earth Excavation per Linear Foot Dollars	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
55	6' 9" × 6' 9"	3,118	14 7	Loam, Clay, Sand and Gravel						3,118 lin ft @ $ 6 75	5.3	1.27
1	7' 4" × 8' 6"	3,627	4 5	Clay						3,627 " " " " 6 15		
25	8' 0" × 8' 0"	1,250	22 6	Clay, Sand and Gravel	Brick	3,112	6"			1,252 " " " " 12.00		
	7' 3" × 7' 3"	1,264								1,260 " " " " 11.00	9 4	1 09
	7' 0" × 7' 0"	920								1,393 " " " " 8 00		
	6' 9" × 6' 9"	485										
44	6' 8" × 7' 0"	592	23 4	Clay, Sand, River Silt and Slate Shale	Macadam	405		31	5 00	592 " " " " 24 00	9 6	2.50
42	6' 0" × 6' 8"	380	10 4	Sand, Gravel, Clay and Slate Shale Rock				300	5 00	84 " " " " 19 25		
										150 " " " " 8.25		
										146 " " " " 48 30		
										8 " " " " 162 50		
48	6' 3" × 6' 3"	836	18 4	Clay, Sand and Gravel	Brick	823	6"			3,599 " " " " 6.75	5.9	1.14
	6' 0" × 6' 0"	2,763			Macadam	2,736						
3	6' 1½" × 6' 6"	290	10 5	Clay and Gravel						290 " " " " 3 85	3.6	1.07
4	5' 4½" × 5' 8"	2,189	21.9	Clay, Sand and Gravel	Macadam	1,300				2,189 " " " " 4 27	6 7	0.65
	6' 1½" × 6' 6"	2,491								361 " " " " 1 60		
										2,130 " " " " 16 00		

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu. yds)	Cost of Rock per Cu yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
28	3'3"	3,124	21.3	Clay, Sand, Gravel and Rock				565	190@ 4.00 375@ 8.50	862 lin. ft @ $ 4.00	2.9	1.88
										270 " " " " 7.00		
	12"	148								988 " " " " 3 75		
	36"	64								1,120 " " " " 7 74		
	30"	40								(Tunnel)		
	6'1½" x 6'6"	156	25.2							153 lin ft @ $18.00		
8	5'6½" x 5'10"	2,023	18 9	Loam, Clay, Sand and Gravel	Brick	640	6"			2,023 " " " " 4.45	5.8	0.71
	5'6"	1,734			Macadam	2,080				1,734 " " " " 3.70		
41	5'2" x 4'11"	2,720	15.4	Loam, Clay, Sand, Gravel and Rock				1,600	5.00	673 " " " " 16.00	4.4	2.27
	4'0"	107	20.0							2,047 " " " " 8.00		
43	5'2" x 4'11"	1,042	20.5	Filled Ground, Sand and Gravel	Granite Block	385				1,054 " " " " 13.25	5.8	2.20
	4'6" x 4'6"	377								365 " " " " 11 25		
7	4'11" x 5'2"	1,707	7.7	Clay and Rock				200	1.00	1,715 " " " " 1.50	2.1	0.71
	2'7" x 2'9"	1,448	6.9							1,440 " " " " 0.80	1.5	0.53
16	4'6" x 4'6"	2,427	23.3	Clay, Sand and Gravel	Brick	60	6"	5	5.00	1,420 " " " " 8.75	6.1	1.31
					Macadam	447				1,007 " " " " 7.00		
61	66"	557	10.5	Clay and Rock	Macadam	1,156		1,470	5.00			

TABLE 34—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds)	Cost of Rock per Cu yd (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd, Dollars
61	57"	1,438	10.5	Clay and Rock	Macadam	1,156		1,470	5 00	2,003 lin ft @ $ 5.00	2.4	2 08
	48"	872								1,588 " " " " 5.00		
	39"	712										
58	60"	2,160	14 1	Clay and Sand						2,180 " " " " 4.76	3.8	1.24
	57"	34								29 " " " " 3.00		
	48"	826	11 6							826 " " " " 3 38	3 2	1.05
	39"	740	9 2							740 " " " " 2.50	2.1	1 19
80	6'0"	48	13 2	Clay and Sand	Macadam	793						
	5'0"	700								770 " " " " 5.15	4 4	1 17
	33"	22										
72	5'0"	3,239	18.8	Clay, Sand and Gravel				5	7 00	3,239 " " " " 7.44	5.3	1.40
18	60"	817	13 4	Clay and Rock				1,755	4.00	1,610 " " " " 2 53		
	54"	363								939 " " " " 3.30		
	51"	363										
	48"	381								453 " " " " 5.82		
	42"	378										
	30"	555								13 " " " " 15 39		
35	4'6" x 4'6"	63	22.0	Clay, Sand and Gravel	Macadam	627				1,275 " " " " 7 50	5.2	1.28
	4'0"	1,212								1,655 " " " " 6.00		
	3'3"	1,655										

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds.)	Cost of Rock per Cu. yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
9	62"	2,092	16.3	Loam, Clay, Sand and Gravel	Brick	345	6"			2,090 lin ft @ $3.40	5.0	0.68
	52"	1,071	10.9		Macadam	4,456				2,588 " " " " 2 00	2.6	0.77
	45"	607										
	39"	510										
	30"	400										
	18"	217										
49	60"	2,090	18.3	Clay and Sand	Asphalt	50	6"			2,100 " " " " 6.49	4.7	1.36
	42"	1,810								1,800 " " " " 6.33		
13	54"	1,245	13.6	Clay, Sand and Gravel	Granite Rock	773	6"			2,187 " " " " 2 90	3 7	0.78
	51"	479			Macadam	1,259						
	45"	463			Brick	155						
17	54"	449	11 3	Clay and Rock	Macadam	1,959	6"	50	6.00	1,870 " " " " 2.01	2.6	0.93
	42"	390			Brick	10						
	39"	848										
	36"	1,564								1,390 " " " " 2.68		
	27"	158								149 " " " " 5.04		
32	54"	958	21 3	Sand, Gravel and Clay	Brick	579	6"			958 " " " " 5.39	6.3	0.86
					Asphalt	31	6"					
65	54"	437	21.3	Clay, Sand and Gravel	Brick	543	6"			456 " " " " 10.50	5.1	2.06
	48"	604	16.8							604 " " " " 9.85	6.4	1.54
	45"	19										

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu. yds)	Cost of Rock per Cu. yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
64	51"	1,447	15.8	Loam, Clay and Sand	Asphalt	2,219	6"			1,447 lin. ft @ $8.85	4.6	1.92
	33"	1,720	13.3		Brick	2,587	6"			1,745 " " " " 6.20	2.7	2.29
	24"	995	10.8							1,570 " " " " 4.25	1.7	2.50
	18"	670								70 " " " " 7.00		
52	48"	738	9.1	Sand, Gravel and Clay	Brick	1,970	6"			1,121 " " " " 3.50 849 " " " " 3.00	2.1	1.56
	42"	383										
	33"	849										
77	48"	1,425	15.7	Clay and Sand	Brick	1,471	6"			1,425 " " " " 9.30	4.1	2.05
	42"	1,005			Asphalt	959	6"			1,005 " " " " 7.10		
	30"	30								30 " " " " 10.00		
83	45"	784	13.2	Clay, Sand and Gravel	Unimproved					788 " " " " 4.90	3.1	1.57
	15"	228								230 " " " " 1.50		
15	45"	567	10.7	Clay and Sand	Brick	190	6"			1,462 " " " " 1.50	2.2	0.58
	42"	412										
	39"	464										
	33"	421								1,290 " " " " 1.00		
	24"	402										
	24"	486	6.5		Asphalt	1,890	6"					
10	42"	990	12.8	Clay, Sand and Gravel	Boulders	1,457				1,457 " " " " 2.40	3	0.80
	36"	467										

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds)	Cost of Rock per Cu yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
26	42"	1,168	11.5	Clay and Rock				750	1.10	2,162 lin ft @ $2.29	2.8	0.83
	39"	561								708 " " " " 2.41		
	36"	1,180								39 " " " " 2.56		
37	39"	428	8.1	Clay and Sand	Macadam	444	6"			1,235 " " " " 1.44	1.6	0.90
	33"	420			Oil Macadam	791						
	27"	387										
60	3' 3"	955	21.2	Clay	Asphalt	397	6"	10	5.00	942 " " " " 12.00	4.5	1.71
	2' 9"	2,248								438 " " " " 7.15		
										1,075 " " " " 5.00		
										748 " " " " 6.50		
73	3' 3"	955	21.2	Clay	Asphalt	397	6"	10	5.00	942 " " " " 24.00	4.4	3.36
	2' 9"	1,682								438 " " " " 12.00		
										682 " " " " 7.50		
										748 " " " " 12.00		
68	36"	102	7.5	Clay and Fill	Brick	581	6"			102 " " " " 4.00		
	20"	1,040			Macadam	561				1,040 " " " " 1.85	1.1	1.62
84	36" and 10"	1,210	8.5	Clay and Rock								
	33" " 10"	274										
	27" " 10"	935										
	24" " 10"	1,220						1,430	4.00	4,220 " " " " 2.75	1.8	1.53
	22" " 10"	217										
	20" " 10"	364			Macadam	83						

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907-1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds)	Cost of Rock per Cu yd (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
31	39"	32	9.8	Clay, Sand, Gravel and Rock	Macadam	188		500	4 20	1,385 lin. ft @ $3.50	1.8	1.44
	30"	1,293								906 " " " " 1.20		
	24"	906										
12	24"	1,330	12.4	Loam, Clay, Sand and Gravel	Boulders	1,876				723 " " " " 2.36	2.1	0.97
	36"									607 " " " " 1.65		
		546								546 " " " " 2.38	2.6	0.92
19	36"	351	11.6	Clay and Rock	Asphalt	50	6"	200	4.00	1,644 " " " " 1.08		
	33"	379			Brick	684	6"			556 " " " " 2.07		
	27"	461										
	20"	1,002			Macadam	480		380	4.50	22 " " " " 5.45		
33	36"	1,463	13.3	Sand and Clay	Brick	30	6"			1,463 " " " " 1.90	2.5	0.69
	24"	473			Macadam	1,906				473 " " " " 1.20		
46	33"	888	11.2	Sand and Clay	Macadam	2,217				908 " " " " 2.80	2.0	1.15
	30"	402								881 " " " " 2 10		
	24"	479			Asphalt	230	6"			658 " " " " 1.90		
	22"	678										
59	33"	520	10.7	Clay and Rock				1,300	6.00	725 " " " " 1.50		
	27"	253										
	24"	471										
	24"	465								637 " " " " 1.80		

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY, 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu. yds)	Cost of Rock per Cu yd (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
59	20"	122										
	18"	352										
	15"	241								715 lin ft @ $2.40		
	12"	1,034										
	10"	520								471 " " " " 3.00		
	8"	2,881										
86	33" and 10"	646	9.7	Clay and Rock						908 " " " " 2.70		
	27" " 8"	443								1,099 " " " " 3.00		
	24" " 8"	346						820	4.00		3.0	0.77
	22" " 8"	608			Macadam	115				944 " " " " 1 50		
57	18"	684		Clay and Sand	Macadam	1,643				1,155 " " " " 1.48	1.5	0.99
	22"	471										
	30"	488	9.7							478 " " " " 2.35		
50	30"	642	10.1	Clay and Rock	Asphalt	615	6"	1,700	2.00	1,545 " " " " 2.00	2.3	0.87
	27"	886			Macadam	423						
27	30"	348	7.0		Macadam	2,735						
	27"	302	6.3	Clay and Rock	Brick	808	6"	100	4 00	660 " " " " 1.00	1.2	0.83
					Asphalt	378	6"					
22	24"	268	7.8	Clay and Rock	Macadam	885	6"					
	22"	482			Brick	335				1,220 " " " " 1.25 695 " " " " 0.80		

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds)	Cost of Rock per Cu yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
22	18" 30" 24"	470 405 400	9.4	Clay and Sand	Macadam	1,500				805 lin ft @ $1.25	1.6	0.78
24	27" 22"	478 390	10.4	Clay and Sand	Brick Macadam	868 800	6" 6"			478 " " " " 2.45 390 " " " " 1.25	1.7	1.44
23	27" 24" 20"	347 297 290	7.0	Clay, Sand and Gravel	Brick	934	6"			644 " " " " 1.40 290 " " " " 90	1.1	1.14
47	18" 24" 22" 18"	684 274 480 543	7.8	Sand and Clay Sand and Clay	Brick Macadam	684 1,297	6"			684 " " " " 1.05 1,023 " " " " 0.75 274 " " " " 1.50	1.2	0.80
69	24" 20" 18" 12"	1,829 541 909 20	8.2	Loam, Clay, Sand and Rock	Macadam	164		1,200	5.00	1,272 " " " " 2.00 1,675 " " " " 2.00 332 " " " " 2.00 20 " " " " 3.00	1.3	1.54
21	20" 18"	512 418	10.0	Clay and Sand	Macadam Granite Block	900 30				930 " " " " 0.85	1.4	0.61
34	20"	1,000	12.0	Sand and Clay						500 " " " " 1.65 500 " " " " 1.65		
38	20" 18"	500 495	9.3	Clay and Sand	Macadam	995				500 " " " " 1.10 495 " " " " 0.90	1.4	0.73

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu. yds)	Cost of Rock per Cu. yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu yds. Excavation per Foot.	Cost of Earth Excavation per cu yd., Dollars
39	20"	500	9.3	Clay and Sand	Brick	975	6"			500 l.f. @ $1.40	0.9	1.43
	15"	475								475 " " " " 1.18		
40	12"	963	9.5	Clay Gravel and Rock	Macadam	2,116		20	5.00	1,535 " " " " 1.30	1.4	0.73
	10"	955								1,081 " " " " 0.85		
	8"	1,461								763 " " " " 0.65		
63	24 and 8	30	12.4	Clay and Rock	Asphalt	2,367	6"	420	5.50	38 " " " " 8.60	2.6	2.52
	18 " 8	415								365 " " " " 5.60		
	15 " 8	1,017								1,017 " " " " 6.90		
	12 " 8	905								955 " " " " 6.50		
70	22"	300	6.9	Loam, Clay and Rock	Macadam	2,383		700	5.00	3,139 " " " " 0.65	1.0	0.64
	20"	400								230 " " " " 0.50		
	18"	1,862										
	15"	577										
	12"	30										
	10"	194										
74	24" and 8"	338	10.9	Clay, Rock and Fill	Asphalt	2,168	6"	150	6.00	980 " " " " 5.30	1.9	3.10
	18" " 8"	1,011								1,188 " " " " 6.40		
	15" " 8"	547										
	12" " 8"	272										

TABLE 34.—COST OF EARTH AND ROCK EXCAVATION AT LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Length (Feet)	Average Cut (Feet)	Nature of Excavation	Pavement	Length of Pavement (Feet)	Concrete Base	Quantity of Rock (Cu yds)	Cost of Rock per Cu. yd. (Dollars)	Cost of Earth Excavation per Linear Foot Dollars.	Cu. yds. Excavation per Foot.	Cost of Earth Excavation per cu. yd., Dollars
81	22"	1,595		Clay, Rock and Fill	Unimproved			450	4 00	5,245 lin ft @ $1 80		
	18"	1,121										
	15"	1,342										
	12"	391									1.0	1.80
	10"	796										
78	24"	500	8 4	Clay and Sand	Asphalt	554	6"			554 " " " "2 15		
	18"	54									1 2	1.79
79	24"	990	8 1	Clay	Unimproved					990 " " " " 1 00	1.2	0.83
	15"	290								290 " " " " 0.50		
36	4' 0" × 5' 7½"	4,790	9 5	Loam, Clay, Sand and Gravel	Macadam	26						
	4' 9"	695								97 " " " " 1.75		
	6' 0"	1,410										
	3' 10" × 6' 0"	695										
	4' 6" × 6' 0"	695								4,108 " " " "2.75	2.8	0.96
	4' 9" × 6' 0"	630										
	39"	25								690 " " " "2.58		
	18"	683	14.4									
	30"	1,742								835 " " " "5.53	4.8	1.15

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907–1912*

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu. yd. of Concrete	Quantity and Cost of Concrete (Cu. yds)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
2	15' 2" × 15' 6"	Reinforced Concrete	3337	2.99	196 29	65 4	17,000 @ $ 8.12	$ 2.55	$0 0355
	14' 5" × 15' 0"		1841	2 77	190.48	68 8			
	13' 11" × 14' 3"		965	2.11	164.14	77.8			
5	13' 8" × 14' 0"	Reinforced Concrete	4206	2.45	181 54	74.1	10,304 @ 7.86	2.24	0.03
11	13' 6" × 13' 9"	Reinforced Concrete	769	2.08	192 50	92.5	10,840 @ 5.65	2.92	0.032
	13' 3" × 13' 6"		2685	1.86	162.10	87.1			
	12' 11" × 13' 3"		1037	1.82	158.52	87.1			
56	12' 9" × 13' 0"	Reinforced Concrete	1326	1.78	153.40	85 7	2,375 @ 6.94	2.18	0.0255
14	12' 3" × 12' 3"	Reinforced Concrete	2036	147	99.42	68.5	5,050 @ 6.72	2.06	0.03
	12' 0" × 12' 0"		1338	1.51	9886				
20	12' 0" × 12' 0"	Reinforced Concrete	2438	1.47	97.28	65	3,630 @ 6.90	1.95	0.03
6	8' 0" × 8' 0"	Reinforced Concrete	48				3,110 @ 7.10		
	9' 0" × 8' 0"		93				66 @ 9 00		
	10' 1½" × 10' 7"		1897	1.81	111.76	61.7	446 @ 8 40	2.10	0.034
45	10' 0" × 10' 0"	Reinforced Concrete	3530	1 15	99 2	114	3,070 @ 9.70	4.00	0.035
53	6' 0" × 6' 8"	Reinforced Concrete	106	0.81	85.69	171.4	5,770 @ 8.35	5.15	0.03
	9' 0" × 13' 6"		3558	1 59	276 39				

*See page 166 for comment on this table

TABLE 35 — COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907-1912.—(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu. yd. of Concrete	Quantity and Cost of Concrete (Cu yds)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
54	9' 0" x 12' 0"	Reinforced Concrete	1,126	1.37	180 01	104.9	3550 @ $8 30	$3.15	$0.03
	9' 0" x 9' 6"		767	1.26	109 46				
	9' 0" x 9' 0"		830	1.22	103 83				
51	9' 6" x 9' 6"	Reinforced Concrete	1837	1.19	92.0	87.1	2,170 @ 8 50	2.61	0.03
	5' 6" x 5' 6"		3051	0.44	49.2		1,480 @ 8.50		
29	10' 0" x 10' 0"	Reinforced Concrete	115	1.30	92.57	83.3	3,675 @ 7.00	2.58	0.031
	7' 8" x 7' 8"		1997	0.94	78.50				
	7' 0" x 7' 0"		1951	0.79	73.35				
62	7' 6" x 10' 0	Reinforced Concrete	5200	0.98	93.97	95.49	4960 @ 9.00	3.34	0.035
55	8' 3" x 8' 3"	Reinforced Concrete	1727	1 00	90.54	70.9	3,630 9.70	2.13	0.03
	6' 9" x 6' 9"		3118	0.61	36.89				
	7' 4" x 8' 6"	Reinforced Concrete	3627	0.56	47.5	85.7	1,987 @ 6 00	3 00	0.035
25	8' 0" x 8' 0"	Reinforced Concrete	1250	1.00	116.29	112	3,650 @ 7.50	3.08	0 0275
	7' 3" x 7' 3"		1264	0.84	101.84				
	7' 0" x 7' 0"		920	0.79	98.70				
	6' 9" x 6' 9"		485	0.78	95.24				
44	6' 8" x 7' 0"	Reinforced Concrete	592	1.09	109.2	83.1	400 @ 8.50 550 @ 8.00	2.50	0.03

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu yd of Concrete	Quantity and Cost of Concrete (Cu yds)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
42	6' 0" X 6' 8"	Reinforced Concrete	380	0.81	85.69	62.4	630 @ $10.00 280 @ 8.80	$1.87	$0.03
48	6' 3" X 6' 3" 6' 0" X 6' 0"	Reinforced Concrete	836 2763	0.54 0.52	61.49 59.54	112.7	1900 @ 9.25	3.94	0.035
3	6' 1½" X 6' 6"	Plain Concrete	290	0.97			282 @ 8.75		
4	5' 4½" X 5' 8" 6' 1½" X 6' 6"	Reinforced Concrete Plain Concrete	2189 2491	0.71 0.73	57.5	79.2	1753 @ 11.50 1591 @ 7.00	2.38	0.03
28	3' 3"	Reinforced Concrete	3124	0.24	22.23	77	650 @ 9.00 134 @ 12.00	2.31	0.03
8	5' 6½" X 5' 10" 5' 6"	Reinforced Concrete Plain Concrete	2023 1734	0.46 0.47	27.6	63.6	850 @ 6.70 904 @ 6.40	1.59	0.025
41	5' 2" X 4' 11" 4' 0"	Reinforced Concrete Plain Concrete	2720 107	0.90 0.33	55.2	61.2	1335 @ 8.50 45 @ 8.00	1.84	0.03
43	5' 2" X 4' 11" 4' 6" X 4' 6"	Reinforced Concrete	1042 377	0.50 0.41	55.2 52.4	97.8	675 @ 8.50	3.13	0.032
7	4' 11" X 5' 2" 2' 7" X 2' 9"	Reinforced Concrete	1707 1448	0.42 0.17	25.50 7.08	60.7 41.6	973 @ 10.00 26 @ 11.00	1.17	0.021
16	4' 6" X 4' 6"	Reinforced Concrete	2427	0.41	52.4	128.	990 @ 6.75	3.85	0.03

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907-1912.—(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu. yd. of Concrete	Quantity and Cost of Concrete (Cu. yds.)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
61	66"	Reinforced Concrete	557	0.47	26.35	56.06	1260 @ $10.50	$2.24	$0.04
	57"	Reinforced Concrete	1438	0.39	22.31	57.20	30 @ 21.00	2.29	
	48"	Plain Concrete	872	0.34					
	39"	Plain Concrete	712	0.22					
58	60"	Reinforced Concrete	2160	0.44	32.58	74.0	970 @ 9.50	2.10	0.035
	57"		34	0.47	18.81	40.0			
	48"	Plain Concrete	826	0.38			520 @ 10.00		
	39"		740	0.25					
80	6' 0"	Reinforced Concrete	48	0.56			417 @ 12.00	3.80	0.05
	5' 0"	Plain Concrete	700	0.54					
	33"	" "	22	0.17					
72	5' 0"	Reinforced Concrete	3239	0.44	22.37	50.84	1450 @ 12.00	1.78	0.035
18	60"	Plain Concrete	817	0.56			1085 @ 8.65		
	54"		363	0.42					
	51"		363	0.36					
	48"		381	0.33					
	42"		378	0.27					
	30"		555	0.18					

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu yd. of Concrete	Quantity and Cost of Concrete (Cu. yds)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
35	4' 6" X 4' 6"	Reinforced Concrete	63	0.41	52.4	64.6	823 @ $11.00	$1.94	$0.03
	4' 0"		1,212	0.33	28.0				
	3' 3"		1,655	0.24	22.4				
9	62"		2,092	0.45			1,600 @ 7.00		
	52"		1,071	0.32					
	45"		607	0.26					
	39"		510	0.20					
	30"		400	0.16					
49	60"	Reinforced Concrete	2,090	0.46	172	36.9	975 @ 10.25	1.26	0.0342
	42"	Plain Concrete	1,810	0.27			520 @ 10.25		
13	54"	Plain Concrete	1,245	0.36			675 @ 7.50		
	51"		479	0.34					
	45"		463	0.27					
17	54"	Plain Concrete	449	0.42			890 @ 9.00		
	42"		390	0.27					
	39"		848	0.24					
	36"		1,564	0.22					
	27"		158	0.18					
32	54"	Reinforced Concrete Pipe	958	0.13	12.7	98	937 lin. ft. @ 4.50		

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907–1912 —(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu. yd. of Concrete	Quantity and Cost of Concrete (Cu. yds)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
65	54"	Plain Concrete	437	0.43			445 @ $9.65		
	48"	" "	604	0.38					
	45"	" "	19	0.31					
64	51"	Reinforced Concrete	1,447	0.40	33 67	84 17	575 @ 10 50	$3.37	$0.04
	33"	Plain Concrete	1,720	0 19			450 @ 12.00		
	24"	" "	995	0.19					
52	48"	Plain Concrete	738	0 33			535 @ 9.50		
	42"		383	0 27					
	33"		849	0.19					
77	48"	Plain Concrete	1,425	0.38			800 @ 11.00		
	42"	" "	1,005	0 29			21 @ 15.00		
	30"	" "	30						
83	45"	Plain Concrete	784	0 33			280 @ 10.00		
15	45"	Plain Concrete	567	0 33			635 @ 8.00		
	42"		412	0 26					
	39"		464	0.24					
	33"		421	0.19					
	24"		402	0.15					
	24"		486						

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	* Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu yd of Concrete	Quantity and Cost of Concrete (Cu. yds)	Cost of Steel per cu yd of Concrete	Cost of Steel per Pound
10	42"	Plain Concrete	990	0.27			365 @ $7.75		$0.035
	36"		467	0.22					
26	42"	Plain Concrete	1,168	0.27			685 @ 9.00		
	39"		561	0.24					
	36"		1,180	0.22					
37	39"	Plain Concrete	428	0.24			307 @ 9.60		
	33"		420	0.19					
	27"		387	0.16					
60	3' 3"	Reinforced Concrete	955	0.25	24.93	99.8	731 @ 10.00	$3.33	0.0375
	2' 9"	Plain Concrete	2,248	0.19					
73	3' 3"	Reinforced Concrete	955	0.25	24.48	97.92	625 @ 10.90	3.43	0.035
	2' 9"	Plain Concrete	1,682	0.19					
68	36"	Plain Concrete	102	0.22			40 @ 9.00		
84	36" and 10"	Pl Conc and Vit Pipe	1,210	0.22			675 @ 12.00		
	33" " 10"	" " " " "	274	0.19					
	27" " 10"	" " " " "	935	0.15					
	24" " 10"	" " " " "	1,220	0.13					
31	39"	Plain Concrete	32	0.24			405 @ 8.20		0.04
	30"		1,293	0.18					
	24"		906	0.15					

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907—1912.—(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu yd of Concrete	Quantity and Cost of Concrete (Cu yds)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
12	24"	Plain Concrete	1,330	0.22			320 @ $7.90		
	36"		546	0.15					
19	36"	Plain Concrete	351	0.22			275 @ 9.00		
	33"		379	0.19					
	27"		461	0.16					
33	36"	Plain Concrete	1,463	0.22			400 @ 11.50		
	24"		473	0.15					
46	33"	Plain Concrete	888	0.19			335 @ 12.50		
	30"		402	0.18					
	24"		479	0.15					
59	33"	Plain Concrete	520	0.19			250 @ 12.00		
	27"		253	0.15					
	24"		471	0.13					
86	33" and 10"	Pl. Conc. and Vit Pipe	646	0.25			305 @ 10.00		
	27" " 8"	" " " " "	443	0.18			35 @ 16.00		
	24" " 8"	" " " " "	346	0.17					
57	30"	Plain Concrete	488	0.18			95 @ 9.50		
50	30"	Plain Concrete	642	0.18			350 @ 8.00		
	27"		886	0.16					

TABLE 35.—COST OF CONCRETE AND STEEL USED IN SEWERS, LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Size	Material	Length (Feet)	Cu yds of Concrete per Linear Foot (for each Size)	Pounds of Steel per Linear Foot (for each Size)	Pounds of Steel per cu. yd. of Concrete	Quantity and Cost of Concrete (Cu yds.)	Cost of Steel per cu. yd. of Concrete	Cost of Steel per Pound
27	30"	Plain Concrete	348	0.18			210 @ $12.00		
	27"		302	0.16					
22	30"	Plain Concrete	405	0.18					
	24"		400	0.15					
24	27"	Plain Concrete	478	0.16			103 @ 7.25		
23	27"	Plain Concrete	347	0.16			110 @ 7.50		
	24"		297	0.15					
47	24"	Plain Concrete	274	0.15			55 @ 14.00		
69	24"	Plain Concrete	1,829	0.13			270 @ 15.00		
78	24"	Vit Pipe in Concrete	500	0.07			35 @ 7.00		
79	24"	" " " "	990	0.07			70 @ 6.00		
36	4' 0" x 5' 7½"	Reinforced Concrete	4,790			98.6	6,060 @ 8.00	$3.26	$0.033
	4' 9"		695						
	6' 0"		1,410						
	3' 10" x 6' 0"		695						
	4' 6" x 6' 0"		695						
	4' 9" x 6' 0"		630						
	39"		25						

CHAPTER VIII

RATE OF PROGRESS IN BUILDING SEWERS

Upon the rates of progress of excavation, placing masonry and pipe laying depend largely the amount of overhead and supervisory expense, interest on working capital, rentals of machinery and often the amount of profit or loss upon the contract. Many times, the cost of pumping is nearly proportionate to the length of time the work is being prosecuted. The amount of inconvenience to the public may also be about directly proportionate to the same period. In drawing contracts, it is important for the engineer to form an accurate judgment as to the rate of progress which can be attained, that the date of completing the work may be so fixed as to provide a reasonable length of time, thus making it unnecessary to collect liquidated damages for delay and to prevent an unreasonably high charge on account of bonus for completion ahead of the contract date. It is equally important for the contractor to form an accurate opinion of the rate of progress which he can make, in order that he may make an intelligent estimate of the cost of the work and a proposal which shall be low and at the same time provide a reasonable profit.

While it is not possible to give the reader detailed information as to conditions existing in Louisville, it may be helpful to him to know what rates of progress were attained in the building of a number of sewers. Accordingly, such data as are capable of presentation within a reasonable space have been compiled in Table 37, page 201.

In these computations the number of working days has been calculated by subtracting the Sundays from the total number of calendar days from the date of breaking the ground to the date of completion of excavation to grade, and does not include the time consumed in assembling the plant and backfilling, cleaning up and repaving after excavation was completed. The quantity of excavation has been arbitrarily assumed as that included between planes 6 in. on each side outside the extreme limits of the required masonry section. The time needed for placing the concrete was reckoned from the date of placing the first masonry to that of placing the last, and although the quantity of concrete per linear foot given in the table is that required for the sewer barrel, according to the cross-section shown on the plans, the quantity of masonry placed, per day, is computed from the quantity of concrete paid for, including that in manholes and other additional quantities.

Name of tunnel	Size (ft.) Excavation	Size (ft.) Structure (inside)	Material	Date	Shifts	Progress: Max. in single heading, ft. per month	Progress: Av. per day: Headings on which av. is based	Progress: Av. per day: Feet	Cost tunneling per lin. ft.
1. Musconetcong, N. J.	.	. . .	Gneiss, limestone and earth	1872–75	1	144	..	.	. . .
2. Nesquehoning, Penn	.		Rock	1870	1	165		.	. .
3. Hoosac, Mass	.		Rock	1865	1	184			
4. Busk, Colo		15 × 21	Granite	1890	1	202½	2	8 4	.
5. Central, Colo			.		1	222	.		
6. New House, Colo	12 × 12		Porphyry rock	1900	1	244	1	9 2	$21 45
7. Hot Time Lateral, Colo	5 × 7½	.	Rock	.	1	260	.		13 50
8. Stampede, Wash			Basaltic or shale	Apr. 1888	2–10 hr	274			
9. Cascade, Wash	10 × 20		Medium hard granite	1897–1900	3–8 hr	301	1	5 76	
10. Aspen, Wyo	.		Rock		1	306	. .	.	.
11. Melones, Cal	7 × 8		Greenstone (diabase), slate, talc and quartz	1898	3–8 hr	307			11 02
12. Bitter Root Mt., Mont	. ..		Rock		1	333			..
13. Niagara Falls Power Co., N. Y.	.		Rock	.	1	338			
14. Kellogg, Idaho	9 × 11		Quartzite	Oct. 1898	1	354		.	
15. Ouray, Colo.	7½ × 7½		Hard rock	1908	2–8 hr	359	.		12 02
16. Ophelia, Colo			Rock	.	1	395			.
17. Raton, Colo	.		Rock	. . .	1	412			.
18. Sutro, Nev		.		. . .	1	417			
19. Gunnison, Colo	11 × 12		Granite gneiss	Jan. 1908	1	449		.	.
20. Elisabeth, Cal	12 × 12		Porphyry rock	Oct. 1908	3–8 hr	466	.		36 81
21. New Croton Aqueduct, N. Y.	10 × 14	.	. . .	1885	2–10 hr	550	.	.	27 66
22. Catskill Aqueduct, Rondout Pressure Tunnel	17½ circ	14½ dia	Hudson Riv. shale	Nov., 1909	8 hr [2]	488	.	.	. . .
23. Wallkill Tunnel	18 circ		Hudson Riv. shale	Sept., 1910	8 hr [2]	523	. .		. . .
24. Los Angeles Aqueduct, No. 27	9 × 10	.	Medium hard granite	Apr. 1909	..	464		.	. . .
25. Strawberry Tunnel, Utah	9 × 10 ±	7 × 8½	Hard blue limestone to coarse sandstone	Nov., 1910	3–8 hr.	500	.	..	26.70
26. Newton Highlands (Mass.) Trunk Sewer, crossing under Sudbury Aqueduct.	..	48 in. × 53 in.	Fine running quicksand	1904	.	. .	2	9.3	28.53
27. Cleveland Main Intercepter, E. 61st. St. to E. 79 St.	. . . . .	12½ ft. dia.	Hard blue clay	1909–11	1–10 hr	. . . .	1	9±	. . . . .

Name of tunnel	Size (ft.)		Material	Date	Shifts	Progress			Cost tunnelling per lin. ft.
	Excavation	Structure (inside)				Max. in single heading, ft per month	Av. per day		
							Headings on which av. is based	Feet	
28. Syracuse, N. Y., Tunnel Line Sewer.	7 ft 9 in by 5 ft 10 in	33 in dia.	Clay, slate and gypsum	1906	3-8 hr.	....	1?	3 83	......
29. Red Rock Tunnel, Los Angeles Aqueduct.	104 sq ft	.....	Sandstone		3-8 hr	.	1	35 0	6.41
30. Providence, R. I., Sewer Tunnel	.	48 in dia	Dry sand, gravel and quicksand.	.	2-11 hr		1	9.1	....
31. Louisville, Ky., Southern Outfall Sewer, Section G	..	7 ft 8 in by 7 ft 8 in.	Sand and gravel.	1909-11	2 shifts	..	.	9.0	......
32. Laramie-Poudre Tunnel	Min. Sec. 62 sq ft.	7½ × 9½	Mostly granite	Mar., 1911	3-8 hr	653	..	....	......
33. St. Joseph Lead Co., Mining Tunnel.	7 × 12	..	Hard limestone.	.	3-8 hr	455			
34. Woolwich Footway Tunnel.	12 ft 11 in shield	12 ft. 8 in dia outside	Chalk	1910	3-8 hr.	..	1	8 ft. 4 in.	......
35. Newton Pres. Tunnel, Metrop. Water Works.	10± dia.	....	Mostly Roxbury pudding stone	1910-11	Day and night	....	2	20.0	......
36. Chicago Water Works	16 circ.	...	Fine limestone	Apr 1909	..	468	....	....	......
37. Buffalo Water Works	12 × 15	....	Flinty limestone	Mar. 1910		390	....	....	......
38. Goldfield Consol. Co. Laguna Drift.	5 × 7½	...	Dacite	....	2 shifts	260	....	....	......
39. Terryville Tun., N. Y., N. H. & H.R.R	10 × 12 heading	....	Rock, mica and schist	1907-10	2-10 hr	.	1	9.17[3]	......
40. Chicago Water Works Indiana St. Tunnel	.....	7 × 8 ft. 2 in	Clay	..	3-8 hr	..	1	16.0	$7.45[4]
41. Chicago, Western Ave. Tunnel	......	7 × 8 ft. 2 in.	Rock	......	......	......	1	10.0	16.40[4]
42. Brooklyn, N. Y., Gold St. Relief Sewer.	Heading 6 ft.; bot., 10 ft., top, 6 ft., wide	....	Dry sand and boulders	.....	2-8 hr.	......	1	3-6	......
43. Lawrence Ave. Sewer, Chicago	20 ft. dia.	16 ft. dia.	Clay	....	8 hr.[1]	....	2	14.0	......
44. Metrop. Water Works Tunnel under Mystic River.	9 ft. dia.	....	Sand, gravel and boulders.	1900	2-10 hr.	....	....	1.8	......
45. Polk St. Water Tunnel, Chicago	7 ft. dia.	....	Blue clay	....	....	....	[2]	14-16	......

[1] Three shifts miners followed by 3 shifts masons.

[2] Two shifts mining and then 1 placing concrete lining.

[3] Fifty-five feet per week of 6 days.

[4] Cost tunnel excluding shafts.

REFERENCES FOR TABLE 36

1. Eng & Cont, Jan 9, 1908, p 394, Gillette's "Rock Excav," p 329, Stauffer's "Mod Tunnel Pract," p 104
2. Eng. & Cont, Jan 9, 1908, p 394, Gillette's "Rock Excav," p 21
3 Eng & Cont, Jan 9, 1908, p 394, Gillette's "Rock Excav," p 21
4 Eng & Cont, Jan 9, 1908, p 394, Gillette's "Rock Excav" p 327
5. Eng & Cont, Jan 9, 1908, p 394
6. Eng. & Cont, Jan 9, 1908, p 394, Gillette's "Rock Excav," p 350
7. Eng. & Cont., Jan 9, 1908, p 394
8 Eng & Cont., Jan. 9, 1908, p 394, Gillette's "Rock Excav," p 308
9. Eng & Cont., Jan 9, 1908, p 394, Gillette's "Rock Excav," p 323
10. Eng. & Cont., Jan 9, 1908, p. 394
11. Eng & Cont, Jan. 9, 1908, p 394, Gillette's "Rock Excav," p 343
12. Eng & Cont, Jan. 9, 1908, p 394
13 Eng & Cont, Jan. 9, 1908, p 394.
14. Eng & Cont, Jan. 9 1908, p 394; Eng Rec, June 25, 1910, p 800
15. Eng & Cont., Jan. 9, 1908, p 394; Eng Rec, June 25, 1910, p 800
16. Eng. & Cont., Jan. 9, 1908, p 394.
17. Eng. & Cont., Jan. 9, 1908, p. 394.
18. Eng & Cont., Jan. 9, 1908, p 394
19. Eng & Cont., Jan. 9, 1908, p 394. Eng Rec, June 25, 1910, p 800
20. Eng & Cont, Jan 9, 1908, p 394
21 Eng & Cont, Jan 9, 1908, p 394, Gillette's "Rock Excav," p 318
22 Eng Rec., June 25, 1910, p 800. Eng Rec, Jan 1, 1910, p 26
23 Trans Am Soc C E, Dec, 1912, p 765.
24 Eng Rec, June 25, 1910, p 800
25 Eng Rec, Apr 22, 1911, p 432
26 Engr's Report, Newton, Mass, 1904
27 Eng & Cont, Jan 10, 1912, p 44
28 Eng & Cont, Nov 14, 1906, p 138
29 Eng & Cont, Oct 20, 1909, p 320
30 City Engr's Rept, Providence, 1903, p 40 Eng Rec, July 16, 1904.
31 Rept Comrs of Sewerage, Louisville, 1907-10, p 113
32. Trans Amer Soc C E, Dec 1912, pp 742-745
33 Eng Rec, Nov 16, 1912, p. 540
34 Eng Rec, June 17, 1911, p 667
35 Eng Rec, Oct 28, 1911, p 511
36 Eng Rec, June 25, 1910, p 800.
37 Eng Rec, June 25, 1910, p 800.
38 Eng Rec, Dec 31, 1910, p 766
39 Eng Rec, Feb 26, 1910
40 Eng & Cont, July 3, 1912, p 13
41 Eng & Cont, July 3, 1912, p 13
42 Eng Rec, April 9, 1910, p 490
43 Eng & Cont, Feb 2 1907, p 51.
44 Eng News, Sept 26, 1907, p 332
45 Eng Rec, Mar 16, 1907, p 340

The importance of providing machinery best adapted to the work is well illustrated by the progress in excavation made under Contract 2. This work was prosecuted at two openings, the physical conditions being about the same at both, except that Section *a* was about 5 ft. deeper than Section *b*. The machinery, however, was quite different. The cableway used on Section *a* was very heavy and did not prove as well adapted to the work as the stiff-legged derricks used on Section *b*. The quantity of excavation on Section *b* was 239.5 cu. yd. per day whereas on Section *a* it was 186 cu. yd., the rate of progress being 10 ft. and 6.9 ft. per day, respectively.

James Collier, the general superintendent of the National Construction Co., gives the following information concerning the work done by a Buckeye trenching machine in Denver, Colo. In a section where the average cut was about 8–1 2 ft. and the soil was a sandy loam requiring no bracing, the record was this:

Trench, linear feet	18,196 ft.	
Distance cut by machine, ft	17,474 ft	
Time machine in operation, hours	253 25 =	52 per cent.
Time machine idle, shifting, hours	46 00 =	9 per cent.
Time machine idle, repairs, hours	27 25 =	6 per cent.
Time machine idle, other causes, hours	159 50 =	33 per cent.
Total working hours..	486 00 =	100 per cent.
Ave lin. ft cut per hr worked	69 00	
Ave. lin. ft cut per day for total working days	323 00	

The following figures are given for a section where the average cut was from 6 to 8 ft. and the soil was a hard clay:

Distance cut by machine, ft.	8,819	
Time machine in operation, hours.	95 50 =	35 per cent
Time machine idle, shifting, hours	17 50 =	7 per cent.
Time machine idle, repairs, hours	71 .25 =	26 per cent.
Time machine idle, other causes, hours	86 75 =	32 per cent.
Total working hours..	271 00 =	100 per cent.
Ave. lin. ft. cut per working hour	92 3	
Ave. lin ft. cut per day for total working days.	353 00	

Tunnels.—As all work within a tunnel must be done by artificial light, it can be prosecuted as well by night as by day. On this account, it is customary to employ two or even three shifts upon such work, thus greatly increasing the rate of progress. Upon relatively small tunnels, those under 8 ft. in diameter, a rate of progress of driving of from 3 to 10 ft. per shift may be attained in a single heading, the average for such work being perhaps 5 ft. If two shifts per day are employed the excavation may occupy one and the placing of masonry the other so that the net progress per shift will be one-half that of driving the tunnel, or say 5 ft. per day on the average. The information relating to rate of progress in tunneling in different materials which is given in Table 36 has been obtained from many sources. An inspection of the table will show that the cost as well as rate of progress depends on so many conditions that even an experienced engineer will be reluctant to claim close accuracy for his estimates of what a tunnel in some materials or under some working conditions will cost. In such cases, the practice of the best engineers is to make their figures decidedly liberal, and then hope the actual costs will not overrun them.

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu. yds.)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu yds.)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds.)	Excavation per Working Day (cu. yds.)	Method of Excavation
2	a	15'2" x 15'6"	2,850	2.99	196.29	21.2	6.9	604	194	34.6	26.5	186.0	Stream Shovel and Cableway.
	b	15'2" x 15'6"	487	2.99	196.29	26.7	10.0			29.9	22.5	239.5	Steam Shovel and Stiff Leg Derrick with O.P. Buckets.
		14'5" x 15'0"	1,841	2.77	190.48								
		13'11" x 14'3"	965	2.11	164.14								
5		13'8" x 14'0"	4,228	2.45	181.5	23.54	9.35	432	128	39.3	26.5	281.4	Steam Shovel, Revolving Derrick and Potter Machine.
11		13'8" x 14'0"	50	2.45	181.5	16.67	8.70	395	64	33.3	20.8	152.8	Steam Shovels and Locomotive Crane with O.P. Buckets.
		13'6" x 13'9"	712	2.08	192.5								
		13'3" x 13'6"	3,720	1.86	162.11								
56		12'9" x 13'0"	1,330	1.78	151.66	13.54	7.4	341	62	34.2	21.1	127.7	Scrapers, Locomotive Crane with O.P. Buckets and Potter Machine.
14	a	12'3" x 12'3"	940	1.51	98.9	14.32	9.2	546	69	33.5	19.4	174.0	Scrapers and Stiff Leg Derrick with O.P Buckets.
	b	12'3" x 12'3"	1,099	1.51	98.9	18.89	12.5			35.0	20.3	210.0	
		12'0" x 12'0"	1,362	1.47	98.6								
20		12'0" x 12'0"	2,452	1.47	98.6	17.26	11.50	391	256	34.9	20.2	227.3	Stiff Leg Derrick and O.P. Buckets and Carson Machine.
6	b	10'1½" x 10'7"	1,867	1.81	106.68	12.42	7.3	345	82	41.5	22.3	138.5	Scrapers and Cableway.
	a	9'8" x 8'0"		Variable. Outlet Structure, Progress Dependent upon River Stage									
		8'0" x 8'0"											
45		10'0" x 10'0"	3,590	1.28	97.59	16.24	12.24	584	116	26.8	14.5	176.4	Stiff Leg Derrick with O.P. Buckets.

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
53		9'0" x 13'6"	3,538	1.61	276.39	18.75	11.9	552	93	23.9	16.9	199.0	Scrapers and Stiff Leg Derrick with Clam Shell Buckets
		6'0" x 6'8"	106	0.82	85.69			106	106				
54		9'0" x 12'0"	1,101	1.37	180.01	21.40	16.2	466	125	22.4	12.2	170.9	Scrapers and Locomotive Crane with O P Buckets
		9'0" x 9'6"	792	1.26	109 46			447	30				
		9'0" x 9 0"	824	1.22	103 83			430	349				
51	a	9'6" x 9'6"	1,837	1 19	92.0	9.84	7.6	454	22	26.1	11.9	98.5	Scrapers and Potter Machine
	b	5 6" x 5'6"	3,051	0.46	49.2	5.87	11.8	1,176	270	16.9	5.0	51.7	Scrapers and Locomotive Crane with O P Buckets
29	a	10 0" x 10'0"	254	1.26	91.49	5.52	4.3			33.0	17.4	83.2	Scrapers and Stiff Leg Derrick with O P Buckets.
	b	7'8" x 7 8"	498	0 92	79.26	16.71	17.2			26.2	11.3	64.7	
	c	7'8" x 7 8"	565	0.92	79.26	2.56	2.77						
			Masonry Progress under best Conditions 28 8 ft per week					547	147				
								Tunnel, Excavation averaged 6 1 ft per Day Miners Excavated 4 5 ft per Heading per Shift					
	d	7'8" x 7'8"	925	0 92	79.26	10.58	11.6			25.5	10.3	107.1	Hand and Stiff Leg Derrick with O P Buckets
		7 0" x 7'0"	1,365	0 82	72.94								
62	a	7'6" x 10'0"	3,567	0 98	93.97	20.52	20.3	1,257	308	17.8	8.9	184.0	Stiff Leg Derrick with Clam Shell or O.P Buckets
	b	7'6" x 10'0"	1,605	0.98	93.97	12.94	12.1			14.8	7.4	87.7	
55	a	8'3" x 8'3"	1,689	0 95	90.54	10.62	10.8	390	46	20.5	8.5	97.8	Carson Machines and Hand.
	b	8'3" x 8'3"	29	0 95	90.54	5.22	8.4	588	72				
		6'9" x 6'9"	1,871	0 57	36.89					15.7	5.6	38.0	
	c	6'9" x 6'9"	1,262	0.57	36.89	5.07	8.3			13.7	4.9	39.2	

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu.yds.)	Method of Excavation
1		7'4" × 8'6"	3,627	0.56	47.5					Data Inaccessible			
25		8'0" × 8'0"	1,256	1.00	116.29	13.10	14.3	693	158	22.6	9.4	145.3	Locomotive Crane with O P Buckets.
		7'3" × 7'3"	1,259	0.84	101.84								
		7'0" × 7'0"	923	0.79	98.70								
		7'0" × 6'9"	493	0.78	95.24								
44		6'8" × 7'0"	592	1.09	109.2	1.93	1.3	367	0	23.4	9.6	35.6	Cableway and Stiff Leg Derrick with O P Buckets.
		This Contract was Carried on at Two Openings not Wholly Distinct											
42		6'0" × 6'8"	150	0.81	85.69	1.18	1.5			10.4	7.9		Stiff Leg Derrick.
48		6'3" × 6'3"	836	0.54	61.49	7.40	13.6	696	196	18.4	5.9	72.9	Carson Machine
		6'0" × 6'0"	2,757	0.52	59.54								
3		6'1½" × 6'6"	290	0.97						10.5	Data Inaccessible		
4		6'1½" × 6'6"	2,447	0.73	Work Largely in Tunnel, Remaining Data Inaccessible								Hand, Scrapers and Derrick with O P Buckets
		5'4½" × 5'8"	2,183	0.71	57.5	19.49	25.8	1,058	141	21.9			
28		6'1½" × 6'6"	156	0.61	60.38	547	11.2	488	178	25.2	2.9	65.2	Hand and Cableway.
		39"	3,242	0.24	22.23					21.3			
			1,300 ft of this Sewer was in Tunnel Progress in which was from 24 ft to 38 ft per day										

Table 37.—Rate of Progress of Construction by Contract of Masonry and Pipe Sewers in Louisville, Ky., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu. yds)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu. yds.)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds.)	Excavation per Working Day (cu yds)	Method of Excavation
8	a	5'6½" x 5'10"	2,025	0.46	27.6	5.87	12.3	645	270	20.3	6.1	70.3	Scrapers and Stiff Leg Derrick and O P Buckets.
		5'6"	438	0.47									
	b	5'6"	1,295	0.47		3.88	8.1			16.6	5.2	38.0	Carson Machine.
41	a	5'2" x 4'11"	1,496	0.50	55.2	5.42	10.6	356	144	14.5	4.2	46.1	Derrick and Hand.
		48"	107	0.33									
	b	5'2" x 4'11"	1,224	0.50	55.2	4.88	9.5			16.5	4.8	49.5	Cableway and Hand
43	a	5'2" x 4'11"	1,056	0.50	55.2	3.09	5.6	577	22	20.4	5.9	32.4	Scrapers, Hand and Stiff Leg Derrick.
		4'6" x 4'6"	111	0.41									
	b	4'6" x 4'6"	268	0.41		2.50	6.1			20.4	5.3	31.5	
7	a	4'11" x 5'2"	1,707	0.42	25.50	8.06	19.2	1,145	650	7.7	2.1	27.1	Hand.
	b	2'7" x 2'9"	1,448	0.17	7.08	3.11	18.3			6.9	1.5	23.7	Hand
16	a	4'6" x 4'6"	1,443	0.41	52.4	5.17	12.5	766	417	25.5	6.6	80.0	Carson Machine.
	b	4'6" x 4'6"	982	0.41	52.4	5.09	12.3			20.0	5.2	61.5	Cableway
61		66"	586	0.47	26.35	13.55	47.1	1,250	903	10.5	2.4	99.5	Hand.
		57"	1,406	0.39	22.31								
		48"	870	0.34									
		39"	727	0.22									

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu. yds.)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu. yds.)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu. yds.)	Excavation per Working Day (cu. yds.)	Method of Excavation
58	a	60"	1,540	0.44	32.58	5.56	12.1	605	338	15.5	4.2	50.2	Stiff Leg Derrick.
		57"	18	0.47	18.81								
	b	60"	623	0.44	32.58	5.03	10.9			12.7	3.4	40.4	Hand.
	c	48"	826	0.38		2.66	6.8			11.6	3.2	31.2	Hand.
	d	39"	740	0.25		2.44	9.3			9.2	2.1	20.7	Hand.
80		72"	30	0.56	44.0	7.87	14.3	434	283	13.2	4.4	48.4	Hand and Stiff Leg Derrick with O P Buckets.
		60"	706	0.54									
		33"	888	0.17									
85	a	66"	934	0.61		12.17	20.4	935	578	20.7	7.3	100.3	Scrapers and Stiff Leg Derrick with O P Buckets
		60"	496	0.53									
		54"	22	0.39									
		30"	38	0.18									
	b	30"	813	0.18		4.50	23.9			8.1	1.5	29.7	Hand
72	a	60"	1,434	0.44	22.37	4.74	10.5	950	330	20.0	5.6	65.7	Carson Machine.
	b	60"	984	0.44	22.37	3.79	8.5			18.3	5.1	42.7	Carson Machine.
	c	60"	605	0.44	22.37	2.66	5.9			20.2	5.6	25.2	Stiff Leg Derrick.
	d	60"	215	0.44	22.37	1.68	3.8			15.6	4.3	16.0	Hand
18	a	60"	813	0.56		4.60	8.7			20.8	6.7	49.2	
		54"	365	0.42									

Table 37.—Rate of Progress of Construction by Contract of Masonry and Pipe Sewers in Louisville, Ky., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
18	b	51"	365	0.36		2.79	8.0	663	421	17.8	4.8	40.5	Scrapers Hand and Cableway
		48"	378	0 33									
		42"	49	0 27									
	c	42"	330	0 27		2.13	9 4			9.1	1.8	17 0	
		30"	554	0.18									
35	a	4'6"×4'6"	64	0.41		1.61	3.8	712	106	23 5	6.4	26.0	Cableway and Carson Machine.
		48"	1,202	0.42									
		39"	281	0 33									
	b	39"	1,383	0.33		1 25	3.8			20 3	5.0	18.3	
9	a	62"	2,033	0.45		6.77	14 4	791	533	16 3	5.0	70.0	Potter Machine
		52"	65	0.32									
	b	52"	1,039	0.32		4.24	15.6			11.2	2.7	41.7	
		45"	607	0.26									
		39"	487	0.20									
		30"	416	0.16									
49		60"	2,118	0.46	17.2	6.29	15.9	742	110	18.3	4.7	77.5	Stiff Leg Derrick and Cableway.
		42"	1,787	0.27									
			Construction Made in Two Openings but Data on Individual Openings not Available										

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
13	a	54″	1,245	0.36		5.83	16.2	613	127	14.3	3.9	62.6	Cableway
		51″	479	0.34									
		45″	62	0.27									
	b	45″	401	0.27		3.36	12.2			10.6	2.7	28.2	
17	a	54″	454	0.42		2.85	9.2	818	392	7.3	1.8	16.0	Hand.
		36″	728	0.22									
	b	36″	3	0.22		2.89	11.6			12.8	3.0	31.7	Hand and Scraper Trench Machine
		27″	161	0.18									
		36″	256	0.22									
		42″	388	0.27									
		39″	380	0.24									
	c	39″	455	0.24		2.16	8.6			15.5	3.6	32.0	
	d	39″	15	0.24		1.75	7.5			13.9	3.0	33.4	
		36″	567	0.22									
32		54″	959	0.13		3.28	7.81	318	257	21.3	6.3	61.3	Cableway
65	a	54″	454	0.43		6.26	13.5	546	278	16.8	5.1	36.7	Hand and Stiff Leg Derrick
		45″	19	0.31									
	b	48″	613	0.38		4.22	8.9			23.1	6.4	68.8	

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
64	a	51"	1,449	0.40	33.67	8.08	19.6	585	427	15.8	4.6	81.5	Carson Machine.
	b	33"	1,743	0.19		3.64	18.2	788	694	13.3	2.7	48.8	Hand
	c	24"	900	0.13		1.95	14.5			10.8	1.7	29.7	Hand
52	a	48"	738	0.33		1.64	4.8	685	162	11.2	2.9	14.0	Hand
	b	42"	383	0.27		0.73	2.6			8.4	1.9	5.0	
	c	33"	849	0.19		1.23	7.0			7.5	1.4	8.7	
77		48"	1,455	0.38		15.00	38.5	146	120	15.7	4.1	145.3	Carson Machine
		42"	976	0.29									
		30"	30	0.18									
83		45"	787	0.33		8.09	23.0	560	560	13.2	3.1	89.0	Stiff Leg Derrick with O P Buckets.
15	a	45"	565	0.33		4.03	13.1	1,330	618	12.8	3.2	38.0	Scraper Trench Machine.
		42"	414	0.26									
	b	39"	465	0.24		3.18	13.0			9.3	2.1	22.4	
		33"	15	0.19									
	c	33"	400	0.19		2.32	11.9			8.0	1.6	18.5	
		24"	4	0.15									
	d	24"	399	0.15		1.67	10.8			8.4	1.4	16.5	
	e	24"	485	0.15		2.14	13.9			6.2	1.0	14.1	

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu.yds.)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu.yds.)	Length of Sewer per Working Day (feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu.yds.)	Method of Excavation
10		42"	988	0.27		5.90	20.21	588	301	12.8	3.0	50.6	Hand and Stiff Leg Derrick.
		36"	469	0.22									
26	a	39"	559	0.24		1.49	5.9	812	142	10.9	2.4	15.7	Hand.
		36"	241	0.22									
	b	42"	144	0.27		2.01	8.1			12.2	2.7	21.9	
		36"	556	0.22									
	c	42"	156	0.27		1.22	5.0			11.6	2.6	13.0	
		36"	373	0.22									
	d	42"	869	0.27		2.94	10.3			11.7	2.8	29.0	
		36"	13	0.22									
66	a	45"	34	0.33		1.83	5.3	970	162	26.0	6.0	25.6	Cableway and Hand.
		39"	299	0.26									
	b	30"	675	0.21		3.05	11.4			15.6	3.0	31.6	
	c	30"	1,102	0.18		5.62	26.9			16.2	3.0	62.0	
37	a	39"	465	0.29		2.59	8.6	829	405	9.0	2.2	19.7	Hand
	b	33"	410	0.23		2.51	10.5			8.1	1.7	17.1	
	c	27"	360	0.18		1.75	9.2			7.1	1.2	11.0	
60		39"		0.25	24.93					21.2	4.5	Contract Abandoned, See No 73.	
		33"		0.19									

Table 37.—Rate of Progress of Construction by Contract of Masonry and Pipe Sewers in Louisville, Ky., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs.)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
73		39"	955	0.25	24.48	8.22	27 2	1,409	673	21.2	4.4	124 2	Hand Scrapers, Stiff Leg Derrick with O P Buckets and Hand
		33"	1,682	0.19									
			Construction Made in Five Openings of Indefinite Length This is Completion of Contract No 60										
68		36"	162	0.22		1.95	5.3			7.5	1.1	38 8	Hand
67	a	36"	877	0.26		2.45	7.9	932	405	12.2	2.8	24 1	
	b	36"	2,043	0 26		4.71	15.2			7.6	1.7	27.0	Hand
		33"	40	0.23									
84		36"	1,209	0.22		10.46	49.9	1,760	1,410	8.5	1.8	107.7	Hand and Scrapers
		33"	274	0.19									
		27"	933	0.15									
		24"	1,220	0.13									
					Construction Carried on at Several Points but the Openings were not Distinct								
31		39"	32	0.24		2.20	11.8	563	205	9.8	1.8	29.4	Hand
		30"	1,353	0.18									
		24"	901	0.15									
12		36"	566	0.22		5.57	29.77	975	325	12.4	2.3	54.4	Hand.
		24"	1,310	0.15									

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu yds)	Steel per Linear Foot (lbs)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
19	b	36"	355	0.26		1.26	4.7	437	87	14.7	3.2	13.0	Carson Machine
		33"	379	0.23									
	a	27"	454	0.18		3.32	16.2			6.8	1.2	8.0	Hand
33	a	36"	1,016	0.26		2.93	10.9	1,223	295	13.8	3.0	30.1	Hand
	b	36"	447	0.26		2.35	8.9			11.3	2.4	20.6	
		24"	13	0.15									
	c	24"	456	0.15		1.28	8.0			9.2	1.5	10.9	
76	a	33"	2,127	0.19		6.97	32.66	137	116	8.3	1.4	44.3	Hand
	b	33"	560	0.19		3.31	15.56			Several Short Tunnels.			
30		33"	326	0.19		4.83	6.2	147	9	8.9	2.2	52.1	Hand
46	a	33"	690	0.23		3.11	13.6	1,078	562	10.7	2.2	29.9	
	b	33"	198	0.23		2.21	11.5			11.3	2.2	24.7	Hand
		30"	402	0.18									
		24"	10	0.15									
	c	24"	471	0.15		1.54	10.3			11.6	1.8	29.0	
59		33"	515	0.19		4.46	8.6	440	280	10.7	2.0	50.4	Hand.
		27"	253	0.15									
		24"	467	0.13									

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907-1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonry per Linear Foot (cu. yds)	Steel per Linear Foot (lbs)	Concrete Masonry per Working Day (cu yds)	Length of Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds)	Method of Excavation
86		33" 27" 24"	671 431 337	0 25 0.18 0.17	Construction at Two or More Points but the Openings where not Distinct	5.63	22.4	872	83	9 7	3 0	61.2	Hand, Scrapers and Cableway
57		30"	492	0.18		1.72	8.6	200-	194	9.7	1.5	55.1	Hand.
50		30" 27"	645 886	0.18 0.16		1.94	8.1	688	29	10.1	2.3	40.7	Hand
27	a b	30" 27"	345 279	0.18 0.16		2.12 4.06	11 8 25.4	650	650	7.0 6.3	1.3 1.2	13.5 15.5	Hand.
22		30" 24"	407 389	0.18 0.15		4.02	19.17	612		9.4	1.6	41.0	Hand.
24		27"	483	0.16		3.43	15.9	478	478	10.4	1.7	31.2	Hand
23	a b	27" 24"	349 295	0.17 0.15		3.36 2.52	19 4 16 4	644	644	7.0 6.7	1.2 1.0	19.0 14.0	Hand.
47		24"	274	0.15		9.16	45.7	274	274	7.8	1.2	83.5	Hand

TABLE 37.—RATE OF PROGRESS OF CONSTRUCTION BY CONTRACT OF MASONRY AND PIPE SEWERS IN LOUISVILLE, KY., 1907–1912.—(*Continued*)

Contract Number	Division	Size of Sewer	Length (Feet)	Concrete Masonryper Linear Foot (cu yds)	Steel per Linear Foot (lbs)	Concrete Masonry per Working Day (cu yds)	Lengthof Sewer per Working Day (Feet)	Maximum Length per Month (Feet)	Minimum Length per Month (Feet)	Depth of Sewer (Feet)	Excavation per Linear Foot (cu yds)	Excavation per Working Day (cu yds	Method of Excavation
69		24"	1,829	0 13		5 96	58.1	1,400	192	8.2	1.3	47 5	Hand.
21		Pipe								10.0	1 4	30.7	Hand
34		Pipe								12.1	1 8		Hand
38		Pipe								9.3	1 4		
39		Pipe								9 3	0.9		
40		Pipe								9 5	1.4		
63		Pipe								12.4	2 6	53 2	Hand
70		Pipe								6 9	1.0	34.6	Hand
74		Pipe								10 9	1 9	130 8	
81		Pipe	5,245							8.6	1.0	40 7	Hand.
78		24" Pipe in Concrete	487	0 07		2 78				8.4	1 2	55.0	Hand
79		24" Pipe in Concrete	969	0.07		4.88				8 1	1.2	83.4	Hand
36	a	Combination Sewer and Drain of Varying Size	4,945	1.39	155	14 60	10.5	699	258	9 5	2.8	32.6	Scrapers, Hand and Stiff Leg Derrick with O P Buckets
	b	Sewer Siphon 18" and 2-30" Pipes in Concrete	785	1 05		3. 76	3.6			14.4	4.8	17 7	

CHAPTER IX

THE SHEETING AND BRACING OF TRENCHES AND TUNNELS

The shoring of trenches consists of placing braces across them to hold their banks in normal position, and often involves sheathing the banks with plank, commonly called "sheeting," held in place by longitudinal timbers called "rangers" and by cross-braces.

The most common types of such work are vertical sheeting, horizontal or box sheeting, poling boards, stay-bracing and skeleton sheeting, which are defined on pages 215, 232, 236 and 237.

The method of shoring trenches is usually left to the judgment of a foreman in charge of the work. In many cases it is inadequately done, which results in delay, unnecessary expense and damage. The subject is here treated from both the theoretical and practical points of view, and a number of illustrations are given, from trenches actually constructed, to show the best methods adopted in practice and some of the results of lack of care in placing the sheeting and shoring.

Necessity for Shoring Trenches.—Trenches may be excavated in most materials to a depth of 3 to 6 ft. without much danger of the banks caving. Sometimes in certain materials, such as hardpan, excavations may be made to great depths, 12 to 20 ft., without much danger of accident. Usually, however, it is necessary to shore the banks of trenches thoroughly for the protection of the workmen and to make progress possible. As sewers are generally built in streets where water and gas pipes and other underground structures have already been laid, and sometimes in paved streets in which there are car tracks and where high structures follow the building lines without break, it is necessary to prevent the caving of the banks and the settlement of the adjacent ground, because of the danger to these structures.

Many practical sewer builders often take chances on this part of the work, to reduce cost, trusting that they will not meet with loss of life or property. Many unfortunate examples have proved this a short-sighted policy. In one instance, a contractor, because he had them in stock, used 6 × 6 in. timbers for shoring a deep and treacherous trench rather than go to the expense of purchasing the larger timbers which were needed for this particular work. As a result, the timbers gave way during a heavy rain, the banks slumped enough to cause a break in an adjacent water-main, and the whole accident resulted in a loss of several hundred dollars more than the extra cost of shoring the trench with heavier timbers would have been. Accidents such as this, however, are much more often due to the improper handling of the work than to the selection of improper methods and too light timbering, as, for instance, in another case in which carelessness in holding the banks resulted in slight settlement which caused the breaking of a water-main a few feet back of the sheeting. This accident resulted in the unnecessary loss of about $5000 and several weeks' delay to the work.

It is well to have a trench so timbered and protected as to be safe at all times and to anticipate storms which may cut away the banks and cause damage unless the shoring is in good condition. For this reason it is well to place a low bank of earth along the side and across the ends of the trench, to prevent surface water from flowing into the trench and cutting away the earth behind the sheeting. This does not involve much expense and may result in avoiding serious loss.

The exercise of good judgment, acquired by ample experience, is required to determine when shoring is needed and what method should be adopted. There are no rules by which the inexperienced can determine the depth to which a trench can be excavated without the use of sheeting, or before sheeting should be put in place. It is not unusual to find uneducated superintendents and foremen with many years of practical experience, who are capable of rendering judgment upon these subjects superior to that of the educated engineer.

TYPES OF SHEETING AND BRACING

Vertical Sheeting.—Vertical sheeting, although usually more expensive where other methods can be adopted with equal safety, is the type most commonly used on sewer work and particularly on deep and difficult work, and in trenches in dry running sands, gravels, and quicksand. Where trenches are excavated in improved streets under conditions making it important to prevent settlement on account of danger to pipes and other underground structures, pavements, and abutting buildings, it is often unwise to attempt to use the other and generally less expensive methods of shoring.

It is desirable to excavate the trench as deep as possible (usually 3 to 6 ft.) without endangering the banks before placing the sheeting. When the trench is excavated to this depth the first set of rangers (which should usually be about 1 ft. below the surface of the ground) and if possible the second set are put in position against planks placed vertically against the properly trimmed banks at each end and in the center of each ranger. The end planks should be so placed as to come flush with the ends of the rangers. Having placed the rangers in position and supported them temporarily, the braces are driven, or the jacks made up, so as to hold the two opposite rangers in their proper position.

Braces should be cut so as to require reasonably hard driving and to set the planks back slightly into the bank, as otherwise there will be danger of the braces becoming loose and ineffective. The banks should then be trimmed plumb and to a line, which will require the rest of the sheeting to be driven lightly, to get it down between the banks and the rangers to the bottom of the excavation thus far made. Some practical sewer builders maintain that it is better to hold the top and second sets of rangers temporarily in place until all the sheeting planks have been placed behind them against the bank, and then drive the braces or make up the jacks, thus securing a somewhat tighter hold on the banks than where the planks are slipped in behind the rangers after the latter have been finally braced. The former method will generally prove more convenient and will give equally good results if care is taken to so trim the banks that each plank will have a driving fit.

The second set of rangers should be placed as soon as the first set has been secured in position, or better, if conditions will warrant, at the same time that the first set is placed. The vertical distance between the several sets of rangers will depend to some extent upon the local conditions and the character of material, but generally, upon work of moderate size, they should be spaced about 4 ft. on centers. The rangers should be directly over one another, thus allowing the sheeting to be driven plumb. After the rangers are securely braced, lap blocks or cleats made of 2-in. lumber the width of the braces and about 18 in. in length, should be placed on top of and across the joints between the ends of the braces and the rangers and securely nailed to the braces to prevent them from falling if they become loosened. In some cases it may be convenient to attach the cleats to the braces before the latter are driven, thus supporting them while they are being placed between the rangers and driven into their final position. The rangers should generally be placed level, although in side-hill work where the excavation is light and requires the use of only one or two sets of rangers, it may be advantageous to place them parallel to the surface of the street. This should never be done upon deep excavations or where the trenches are in treacherous material.

Rangers will vary in length according to the character of the work being done and particularly the class of machinery used upon the excavation. Common practice, especially in the eastern part of the country, is to make the rangers 16 ft. long, thus fixing the spacing of the braces at a trifle less than 8 ft. on centers, which allows for the convenient use of certain types of trench machines. Upon heavy work it may be advisable to use somewhat longer rangers, thus giving more room between braces for the operation of excavating machinery.

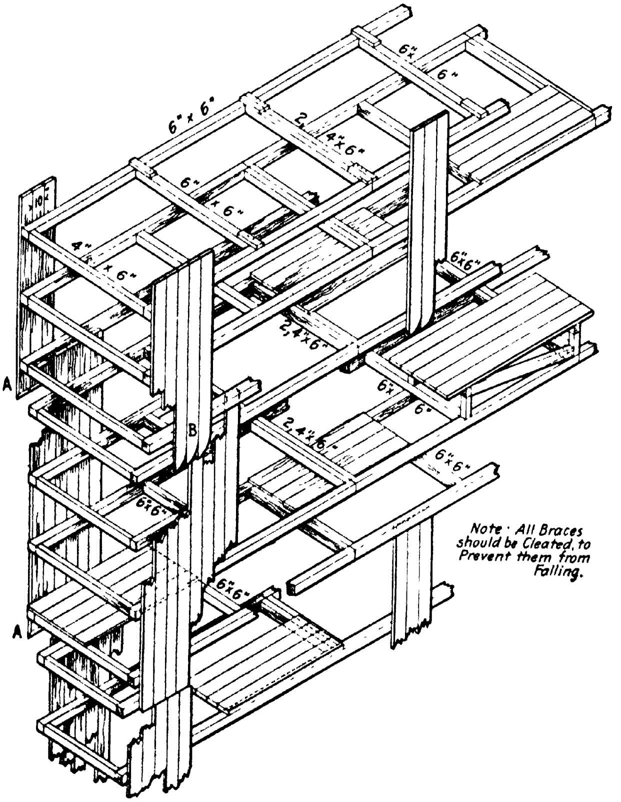
It will generally be found advisable to use three braces upon each set of rangers, one at the center and one at each end, although some practical sewer builders use but a single brace to hold the ends of two abutting sets of rangers, a 2-in. block being used at the end of the brace to cover the joint between the two rangers. By the former method each section of trench will act independently of the adjacent sections, whereas if the end braces engage upon the abutting sets of rangers, a slipping of one set is likely to affect the next set. Where two braces are used at the joints between rangers, some saving in lumber may be effected by making them of somewhat thinner stock than the center braces, as for example, by using 4 × 6-in. braces at the ends and 6 × 6-in. braces in the center.

After the sheeting has been placed in a section and tapped down to the bottom of the excavation, the driving is commenced. One man, sometimes called the "plank lower," should always be stationed in the trench to dig out for and guide each plank as it is being driven. He casts the dirt to the center of the trench and where the material is such as to permit, digs slightly in advance of the plank. After the plank has been driven as far as possible (usually in good digging about 2 ft. below the normal depth of the trench before driving began) it is left and the next one is treated in a similar manner.

As at the beginning of the driving the sheeting usually stands several feet above the ground, platforms constructed of planks loosely laid upon wooden horses are provided at a suitable height upon which the plank drivers may stand and work to advantage. These horses may be conveniently made about 6 ft. high with horizontal cleats about 18 in. apart, so that the platform may be lowered from cleat to cleat as the planks are driven.

In relatively narrow trenches, as those from 3 to 8 ft. in width, it will often be found advantageous to alternate the excavation and the placing and driving of the sheeting between contiguous sections of the trench, as the room in the trench in which the two classes of workmen must carry on their labors is somewhat restricted. This method of procedure involves the excavating of two sections of trench at the same time, thus lengthening the work, which in some cases may be impracticable. On the other hand it often happens, especially in trenches in loose gravel and running sand, that it is necessary to drive planks short distances as the excavation progresses, in which case the driving must be done in connection with the excavation.

The position of the bottom of the sheeting relative to the excavation depends largely upon the character of the material being excavated. If the trench is in hardpan or alluvium, the excavation can often be carried considerably below the sheeting without endangering the stability of the banks. In sand and gravel it is necessary to drive the sheeting down at least as low as the bottom of the trench, and in many cases several inches below. In such cases it is always well to have the "plank lower" dig the earth away from the ends of the planks as they are driven, thus making it possible to keep the sheeting at all times somewhat below the general elevation of the bottom of the trench. In fairly wide trenches, where such material is fairly stable, it may be possible to carry the excavation in the central part of the trench from 1 to 2 ft. below the sheeting, care being taken not to dig too close to the sheeting. This aids the "plank lower" in his work of digging the earth away from the planks as they are being driven.

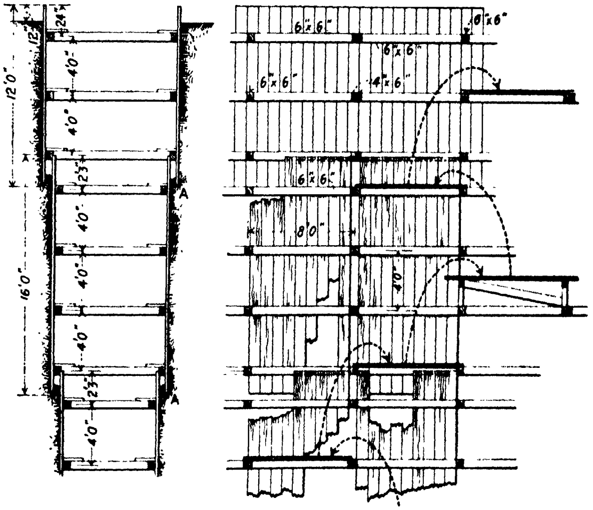


Note: All Braces should be Cleated, to Prevent them from Falling.

FIG. 56—Isometric sketch of typical trench sheeting.

The general method of shoring by means of vertical sheeting, is illustrated by Figs. 56 and 57, which are companion drawings of a narrow trench carried to such depth as to require three sets of vertical sheeting. The rangers are 16 ft. in length and 6 × 6 in. in cross-section, the end braces being 4 × 6 in. and the center braces 6 × 6 in. (see drawing). The first or top set of sheeting is 12 ft. in length, the second 16 ft., and the third as required. The braces are shown cleated, which is good practice upon work of this kind. Staging platforms are shown extending half way and all the way across the trench, as both methods are commonly used. These platforms are supported by the braces or timbers laid across the trench on the rangers.

The most common practice is to use sheeting planks sharpened with "chisel" edges, placed with the beveled side toward the inside of the trench as shown at *A*. In some cases, especially in difficult work where it is necessary to drive the sheeting long distances ahead of the excavation, the planks are beveled in two directions, as shown at *B*, the object being that the planks shall drive straight and that they shall tend to hold tightly against the planks previously driven.



Cross Section.   Longitudinal Section

FIG. 57—Typical trench sheeting.

Figs. 56 and 57 are conventional representations of a sheeted trench. In practice the rangers are rarely spaced with exactness or the planks driven to a uniform depth. In many cases lighter rangers are used, as 4 × 6-in. timbers, and occasionally where the excavation is not to be deep, 2-in. planks are used for rangers. Upon extensive work, however, where the depth of excavation will exceed 10 ft. or where the material to be excavated is such as to make it necessary to shore the banks securely, it is wise to use rangers at least as heavy as 4 × 6-in. timbers, and heavier stock as may appear to be necessary from the local conditions encountered.

As the upper portion of the trench, supported by the first set of sheeting, is the widest, it is wise to make the first set of sheeting the shortest, thus effecting a saving in excavation. Furthermore, the use of relatively short sheeting for the first section avoids the necessity of using horses to any great extent, in connection with the driving of the planks. Stages can be placed upon the rangers in the trench, from which the second and third sets of sheeting can be conveniently driven, even though they are relatively long. An additional advantage in using longer sheeting in the second and third sets is that by the use of guard rails, planks spiked to the braces, the individual planks can be held fairly rigid, so that they do not spring when hit with the driving maul as is the case when the sheeting used for the first set projects a long distance above the ground.

In many cases the length of sheeting adopted for the several sets will be governed by the stock of lumber on hand when the work is begun. If, however, new lumber is to be purchased the dimensions should be specified with a view to its use, and care should be taken to purchase only those sizes which, by avoiding waste, will be economical. While very long sheeting is sometimes used, it is common practice to limit the lengths even of the longer sets to 16-ft. plank. Braces should ordinarily be of the same depth as the rangers.

The use of a short upper set and a longer lower set of sheeting is illustrated by Fig. 59, which shows a trench about 20 ft. in depth, shored by two sets of vertical sheeting. The material excavated was a light alluvium easily held in place, which accounts for its being possible to drive the lower set of sheeting so far below the lowest set of rangers, without materially endangering the stability of the banks. The rangers and braces used upon this work were unnecessarily heavy, but were utilized because they were on hand. Had new timbers been purchased it is not likely that they would have exceeded 6 × 6 in. in dimensions. The sheeting was 2 in. in thickness.

Starting Additional Sets of Sheeting.—After the first set of sheeting has been driven to the full depth to which it is intended to extend, guard rails made of 2 × 6-in. planks are spiked to the lowest set of braces at a distance from the rangers approximately equivalent to the thickness of the sheeting. The second set of sheeting is then passed through the space between the guard rail and the adjacent ranger and placed in its proper position ready for driving. If the sheeting is long, say more than 10 ft., it may be well to place a second guard rail on the second set of

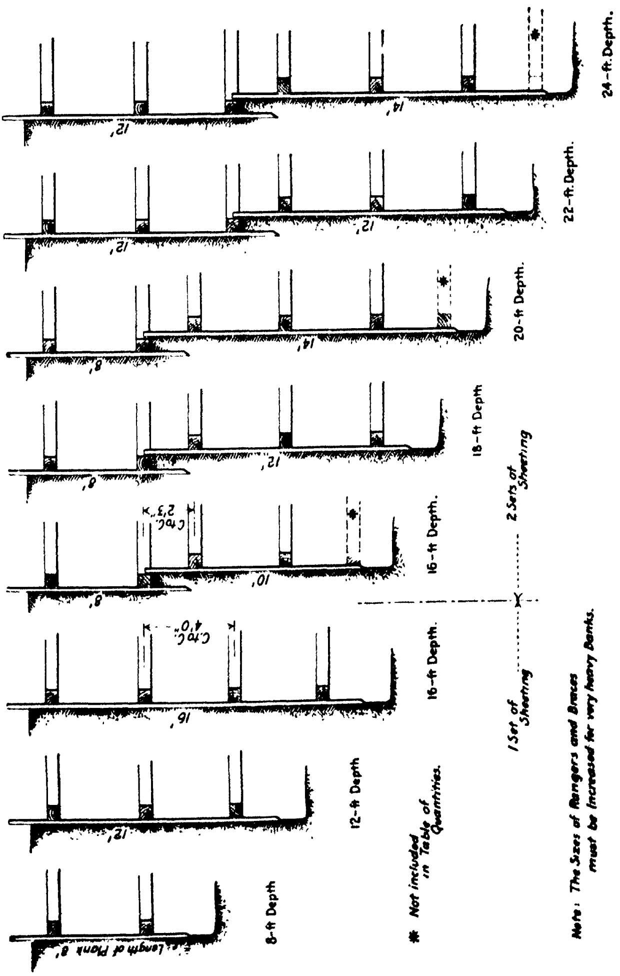


FIG. 58.—A method of shoring ordinary narrow sewer trenches.

braces above the first guard rail. This will hold the upper ends of the planks rigidly and prevent their springing, so that they will be more

Table 38.—Quantities of Lumber Required for Shoring an Ordinary Narrow Sewer Trench, 16 Ft. Long, as Shown in Fig. 58, per Linear Foot of Trench and per Square Foot of Bank Surface

(In Feet Board Measure)

Width of trench at bottom (outside of sheeting), feet	Size of braces and rangers, inches	Depth of trench																	
		8 Ft.						12 Ft						16 Ft (1 set)					
		6 braces	4 rangers	2 in plank	Total, 16 ft trench	Per linear ft of trench	Per sq. ft. of bank	9 braces	6 rangers	2 in plank	Total, 16 ft trench	Per linear ft of trench	Per sq. ft of bank	12 braces	8 rang-ers	2 in plank	Total, 16 ft. trench	Per linear ft. of trench	Per sq. ft of bank
4	4×6	36 00	128 00	512.00	676 00	42 25	2 64	54 00	192 00	768 00	1014 00	63 37	2.64	...	...	...	...	...	...
4	6×6[1]	37 33	192.00	512 00	741 33	46 33	2 89	56 07	288 00	768 00	1112 07	69 50	2 89	74 67	384.00	1024 00	1482.67	92.66	2.89
8	6×6[2]	93.33	192.00	512.00	797 33	49 83	3 12	140 00	288 00	768 00	1196 00	74 75	3 12	186 67	384 00	1024 00	1594.67	99 67	3.12
12	8×8[3]	275 55	341.33	512 00	1128 88	70 55	4 41	413 33	512 00	768 00	1693 33	105 83	4 41	551.11	682 67	1024 00	2257 78	141 11	4 41

		16 Ft (two sets)						18 Ft.						20 Ft.					
		12 braces	8 rangers	2 in plank	Total, 16 ft. trench	Per linear ft of trench	Per sq ft of bank	15 braces	10 rangers	2 in plank	Total, 16 ft trench	Per linear ft of trench	Per sq ft of bank	15 braces	10 rangers	2 in plank	Total, 16 ft. trench	Per linear ft of trench	Per sq. ft. of bank
4	6×6[1]	93.33	384 00	1152 00	1629.33	101 83	3 18	112 00	480 00	1280 00	1872 00	117 00	3 25	112 00	480 00	1408.00	2000.00	125 00	3.12
8	6×6[2]	205 33	384 00	1152 00	1741.33	108 83	3.40	252 07	480 00	1280 00	2012 07	125.75	3.49	252.07	480 00	1408 00	2140.07	133.75	3.34
12	8×8[3]	595 55	682 67	1152 00	2430.22	151 89	4 74	733 33	853 33	1280 00	2866 66	179 16	4.97	733.33	853 33	1408 00	2994 66	187.16	4.68

		22 Ft.						24 Ft.					
		18 braces	12 rangers	2 in. plank	Total, 16 ft. trench	Per linear ft of trench	Per sq. ft. of bank	18 braces	12 rangers	2 in plank	Total 16 ft trench	Per linear ft of trench	Per sq. ft. of bank
4	6×6[1]	140.00	576 00	1536.00	2252.00	140.75	3 20	140.00	576 00	1664 00	2380 00	148 75	3 10
8	6×6[2]	308.00	576.00	1536.00	2420.00	151.25	3 44	308 00	576 00	1664 00	2548 00	159.25	3 32
12	8×8[3]	893.33	1024.00	1536 00	3453.33	215 82	4 90	893.33	1024 00	1664 00	3581.33	223 81	4 66

[1] All end braces 4 in. × 6 in., middle braces same as rangers.

[2] All end braces 4 in. × 6 in., center braces 6 in. × 6 in.

Note The sizes of rangers and braces must be increased for very heavy banks.

[3] All end braces 6 in. × 8 in., center braces 8 in. × 8 in.

readily driven than if held simply by the guard rail near the bottom. Additional sets of sheeting should be started in the same manner.

It is not possible to place and drive planks in a second set of sheeting immediately under the braces of the first set. Therefore, as the excavation is carried down, a space equivalent to the width of the braces above will be left unshored. This space, sometimes called a "window," is frequently closed by placing short horizontal planks behind the adjacent vertical planks. In cases where the material is likely to run, if exposed for a short vertical distance, notched planks are used. These "notches" are usually made of 12-in. planks by cutting out about 6 in. from the upper end of the plank, leaving the lower portion, about 4 ft. in length, the full width of 12 in. These notches are placed under the braces and are driven like the other planks. As they are driven a "window" opens below the braces which must be closed from time to time with horizontal planks set in behind the notches or vertical poling boards fastened to them. Notched planks must be both "rights" and "lefts" so they may be fitted under the double braces from both sides.

Scheme of Shoring and Quantity of Lumber Used upon Light Trench Work.—A system of shoring narrow trenches, from 8 to 24 ft. in depth, is illustrated by Fig. 58. This system has been used upon a large amount of relatively small sewer construction. If the banks are extremely heavy or if the trenches are of greater width it may be necessary to increase the sizes of the rangers and braces. In this system the rangers are assumed to be 16 ft. in length and are held in place by three braces, one at each end and one in the middle of each pair of rangers.

In this sketch the rangers have been placed 4 ft. on centers vertically, except the lower rangers of the upper set and the upper rangers of the lower set, which are 2 ft. 3 in. on centers. The sheeting is shown driven to within 1 ft. of the bottom of the trench.

The quantity of lumber required for the sheeting and bracing of trenches from 8 to 24 ft. in depth, by the system illustrated by Fig. 58, is given in Table 38, which also gives the number of braces and rangers required, and is based upon the use of sheeting 2 in. in thickness. A bill of material for such trenches is given in the four parts of Table 39.

Destruction and Loss of Lumber.—The life of sheeting depends upon the quality of lumber used and the care with which it is handled. It is possible to destroy the best quality of sheeting planks by a single use where the driving is fairly hard, if plank caps and reasonable care are not employed to protect the ends. Where care is used to protect the ends of the planks, the quality of the wood is good, and the driving is not excessively hard, sheeting may be used a large number of times. Upon light work, sheeting may sometimes be used from 10 to 15 times and on more difficult work requiring hard driving, it may not be possible to use it more than 2 or 3 times.

Upon contract work, unless the contractor is reasonably sure of securing additional contracts, it is probable that the entire cost of the sheeting will be charged to the contract upon which it is first used. On the other hand, where work is done by a municipal department by day labor, if reasonable care is taken to avoid damaging the planks, they may be used over and over, and only a portion of the cost of the lumber charged to the first piece of work. In all cases, however, there is a considerable shrinkage of lumber and the cost of resharpening and trimming the old lumber is substantial.

Another cause of shrinkage in lumber is theft, which, in some communities, is a serious matter. In such places, if there is a considerable stock of lumber on hand it may be economy to employ a watchman primarily for the purpose of conserving it.

Taking into consideration all the causes of shrinkage of lumber and the various classes of work upon which it is used, it may not be very far from correct, on the average, to allow for a shrinkage of 20 per cent. of the supply necessary for shoring the trench upon a single piece of work 3000 ft. in length.

Rangers and braces may be used as a rule for a much longer period than the sheeting, although upon very heavy work the effect of excessive pressure and of driving may make it impracticable to use them on the average more than 5 or 6 times; but on light work where the pressures are not excessive and the driving is relatively easy, they may be used

TABLE 39 A.—NUMBER AND LENGTH OF PLANKS REQUIRED FOR SHEETING A TRENCH 96 FT. LONG

Depth of trench, ft	Sets of sheeting	Length of planks, ft	Width of planks, in					
			12	10	9	8	7	6
			Number	Number	Number	Number	Number	Number
8	First	16	96	115	128	144	164	192
12	First	12	192	230	256	288	329	384
16	First	16	192	230	256	288	329	384
16	First	16	96	115	128	144	164	192
	Second	20	96	115	128	144	164	192
18	First	16	96	115	128	144	164	192
	Second	12	192	230	256	288	329	384
20	First	16	96	115	128	144	164	192
	Second	14	192	230	256	288	329	384
22	First	12	192	230	256	288	329	384
	Second	12	192	230	256	288	329	384
24	First	12	192	230	256	288	329	384
	Second	14	192	230	256	288	329	384

Note.—In ordering sheeting, especially where a second set will be required, a supply of assorted sizes should be provided to assist in fitting sheeting to pipes or braces crossing trench. For single sheeting about 5% and for two sets about 20% of number of planks should be assorted sizes.

TABLE 39B.—NUMBER OF 16-FT. RANGERS REQUIRED FOR SHORING A TRENCH 96 FT. LONG

Width of trench at bottom, (outside of 2-in. sheeting), ft.	Size of rangers, in.	Depth of trench, ft.							
		With one set of sheeting			With two sets of sheeting				
		8	12	16	16	18	20	22	24
3	4×6	24	36	48	48	60	60	72	72
4	4×6	24	36	48	48	60	60	72	72
4	6×6	24	36	48	48	60	60	72	72
5	6×6	24	36	48	48	60	60	72	72
6	6×6	24	36	48	48	60	60	72	72
7	6×6	24	36	48	48	60	60	72	72
8	6×6	24	36	48	48	60	60	72	72
9	6×6	24	36	48	48	60	60	72	72
10	8×8	24	36	48	48	60	60	72	72
11	8×8	24	36	48	48	60	60	72	72
12	8×8	24	36	48	48	60	60	72	72

TABLE 39C.—NUMBER OF PIECES AND LENGTH OF TIMBER REQUIRED FOR BRACING A TRENCH 96 FT. LONG, WITH SINGLE SET OF SHEETING

(Stock timber assumed to be 12, 14, 16, 18 and 20 ft. long)

Width of trench at bottom, (outside of 2-in sheeting), ft	Size of rangers, in	Size of braces, in	Depth of trench					
			8 ft		12 ft		16 ft.	
			Number	Length, ft.	Number	Length, ft	Number	Length, ft.
3	4×6	4×6	6	12	9	12	.	.....
4	4×6	4×6	9	12	9	18	..	..
4	6×6	4×6	4	16	6	16	8	16
		6×6	2	16	3	16	4	16
5	6×6	4×6	8	12	12	12	16	12
		6×6	4	12	6	12	8	12
6	6×6	4×6	8	14	12	14	16	14
		6×6	4	14	6	14	8	14
7	6×6	4×6	12	12	18	12	24	12
		6×6	6	12	9	12	12	12
8	6×6	4×6	8	20	12	20	16	20
		6×6	4	20	6	20	8	20
9	6×6	4×6	12	16	18	16	24	16
		6×6	6	16	9	16	12	16
10	8×8	6×8	12	18	18	18	24	18
		8×8	6	18	9	18	12	18
11	8×8	6×8	12	20	18	20	24	20
		8×8	6	20	9	20	12	20
12	8×8	6×8	24	12	36	12	48	12
		8×8	12	12	18	12	24	12

TABLE 39 D.—NUMBER OF PIECES AND LENGTH OF TIMBER REQUIRED FOR BRACING A TRENCH 96 FT. LONG WITH TWO SETS OF SHEETING. (Stock timber assumed to be 12, 14, 16, 18 and 20 ft. long)

Width of trench at bottom, (outside of 2-in sheeting), ft.	Size of rangers, in.	Size of braces, in	Depth of trench																			
			16 ft				18 ft				20 ft.				22 ft				24 ft			
			First set of sheeting		Second set of sheeting		First set of sheeting		Second set of sheeting		First set of sheeting		Second set of sheeting		First set of sheeting		Second set of sheeting		First set of sheeting		Second set of sheeting	
			No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft	No	Length, ft.
3	4×6	4×6																				
4	4×6	4×6																				
4	6×6	4×6	6	16	4	16	6	16	6	16	6	16	6	16	12	12	6	16	12	12	6	16
		6×6	3	16	2	16	3	16	3	16	3	16	3	16	6	12	3	16	6	12	3	16
5	6×6	4×6	6	20	8	12	6	20	12	12	6	20	12	12	9	20	12	12	9	20	12	12
		6×6	3	20	4	12	3	20	6	12	3	20	6	12	6	16	6	12	6	16	6	12
6	6×6	4×6	12	12	8	14	12	12	12	14	12	12	12	14	18	12	12	14	18	12	12	14
		6×6	6	12	4	14	6	12	6	14	6	12	6	14	9	12	6	14	9	12	6	14
7	6×6	4×6	12	14	12	12	12	14	18	12	12	14	18	12	18	14	18	12	18	14	18	12
		6×6	6	14	6	12	6	14	9	12	6	14	9	12	9	14	9	12	9	14	9	12
8	6×6	4×6	12	16	8	20	12	16	12	20	12	16	12	20	18	16	12	20	18	16	12	20
		6×6	6	16	4	20	6	16	6	20	6	16	6	20	9	16	6	20	9	16	6	20
9	6×6	4×6	12	18	12	16	12	18	18	16	12	18	18	16	18	18	18	16	18	18	18	16
		6×6	6	18	6	16	6	18	9	16	6	18	9	16	9	18	9	16	9	18	9	16
10	8×8	6×8	12	20	12	18	12	20	18	18	12	20	18	18	18	20	18	18	18	20	18	18
		8×8	6	20	6	18	6	20	9	18	6	20	9	18	9	20	9	18	9	20	9	18
11	8×8	6×8	24	12	12	20	24	12	18	20	24	12	18	20	36	12	18	20	36	12	18	20
		8×8	12	12	6	20	12	12	9	20	12	12	9	20	18	12	9	20	18	12	9	20
12	8×8	6×8	24	12	24	12	24	12	36	12	24	12	36	12	36	12	36	12	36	12	36	12
		8×8	12	12	12	12	12	12	18	12	12	12	18	12	18	12	18	12	18	12	18	12

from 15 to 20 times with very little waste. On the other hand, the varying widths of trench in any piece of work may seriously limit otherwise possible repeated use of the braces. For this reason, screw jacks may prove less expensive.

Instances of Trench Shoring from Practice.—The following illustrations of shored trenches, Figs. 59 to 74 inclusive, were prepared from measurements of actual trenches excavated upon sewerage work in Louisville, Ky. The Louisville sewers constructed under the direction of J. B. F. Breed, as Chief Engineer, and one of the writers as Consulting Engineer, are illustrative of recent practice in this class of construction. The diagrams were prepared under the immediate direction of Frank C. Williams, Resident Engineer, who has also furnished other data contained in this chapter, and Howard S. Morse and Harrison P. Wires, Resident Engineers upon this work. It is important to note that very little ground water was encountered in most of this work, even in the deepest trenches.

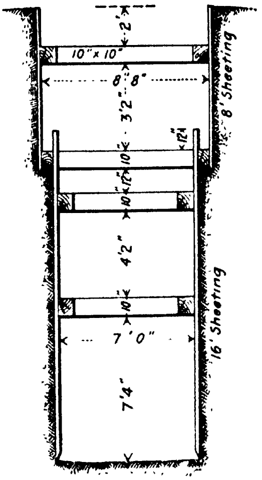


FIG. 59.—Vertical sheeting for 5-ft. sewer.

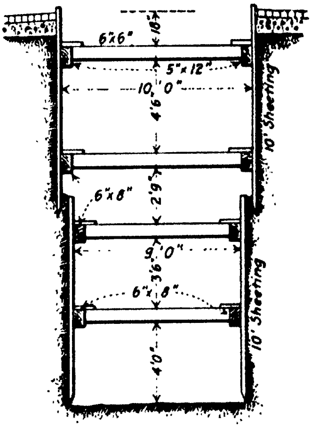


FIG. 60.—Vertical sheeting for 6-½-ft. sewer.

In Fig. 60 is shown the timbering used to support the banks of a trench excavated in alluvium, which was so stable that the planks could be driven safely without bracing to a depth of 4 ft. below the bottom rangers. The braces were all 6 × 6 in. This illustration shows two things to be avoided; first the weakness in the trench shoring between the second and third rangers, and second, the use of braces of less depth than the rangers. While under the conditions encountered on this work, the shoring shown proved satisfactory, it is usually wise to place the lowest rangers on the first set of sheeting fairly close to the bottom of the sheeting, allowing the latter to project from 6 to 12 in., and to keep the first rangers on the lower set of sheeting within 6 to 12 in. of the top of the planks, for the reason that where the banks are heavy there is a tendency for the sheeting to give way between these two sets of rangers. This trench was over 18 ft. in depth.

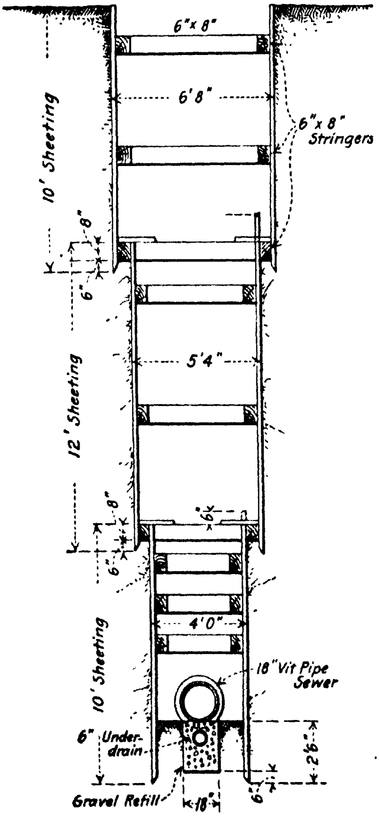


FIG. 61.—Trench in wet clay with sand pockets.

The shoring of a trench about 30 ft. in depth in wet, running, sandy clay, is shown in Figs. 61 and 62. The banks of this trench were of such a nature that the pressure exerted upon the timbering was unusually great, yet no distress was noted.

The bracing used to support one of the heavier trenches, in which a sewer 14 ft. by 13 ft. 8 in. was constructed, is shown in Fig. 63. Three sets of sheeting were used, 12 ft., 16 ft. and 16 ft. in length respectively. The top ranger was 8 × 8 in., and the rangers below it on the first and second sets of sheeting were 8 × 10 in. All of the rangers used upon the third or bottom set of sheeting were of 10 × 10-in. timbers. The braces were of the same dimensions as the corresponding rangers, and each brace was equipped with a jack at one end, the braces being placed against the rangers on one side of the trench and held in position by cleats, until the other ends were jacked against the opposite rangers.

This was a very heavy trench, the upper portion of it being in light alluvium and the lower portion in moist fine sand. The banks exerted great pressure upon the timbering and some settlement resulted. Upon a portion of the work all sheeting, rangers and braces were left in place after the work was completed, as it was feared that there would be considerable settlement of the adjacent street and possibly of buildings, if the timber was removed.

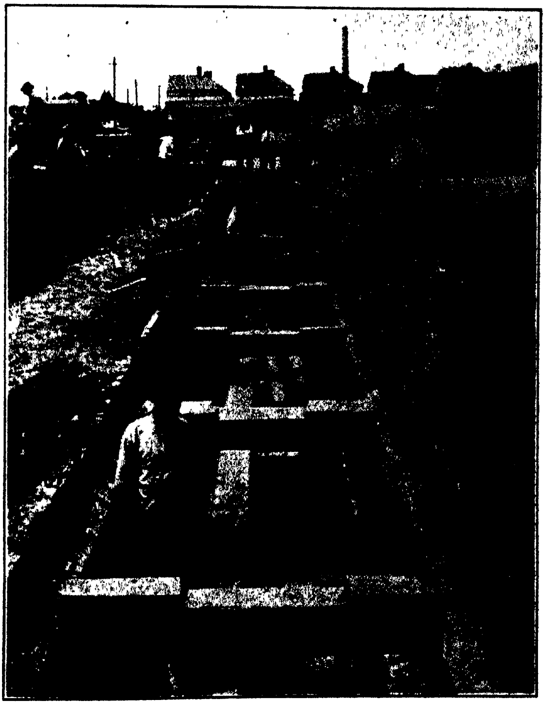


FIG. 62.—View of trench shown also in Fig. 61.

Some of the difficulties encountered upon heavy work are illustrated by Fig. 64. The upper 8 ft. of this trench was in yellow clay or alluvium, below which it was in medium fine sand and fine gravel. No ground water was encountered.

There was considerable settlement of the banks at the point represented by this sketch, and it was necessary to insert an extra ranger with braces, as shown at *A*. Difficulties of this kind are frequently encountered because of lack of care in bracing the trench as excavation progresses, and lack of a sufficient number of rangers. It also seems probable that tighter bracing can be secured by the use of wedges than by the jack screws sometimes used. The rangers and braces upon this work were originally placed level.

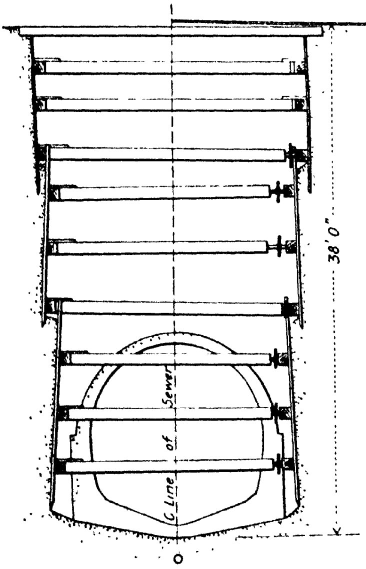


FIG. 63.—Trench for sewer 13 ft. 8 in by 14 ft.

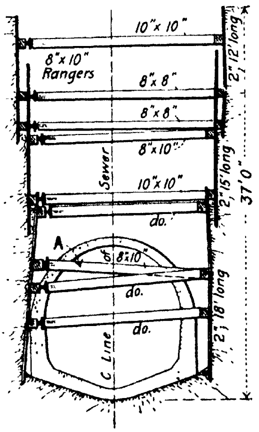


FIG. 64.—Trench for sewer 14 ft. 6 in. by 13 ft. 3 in.

In Fig. 65 are shown conditions similar to those illustrated in Fig. 64.

Fig. 66 is a sketch of the cross-section of a trench in which a 12-ft. semi-elliptical sewer was constructed. It will be noticed that the three braces supporting the lowest set of sheeting came in the way of the concrete. The concrete of this sewer was placed in two operations, the invert and bench walls to a height just below the lowest brace being poured in one operation, and the arch above the bench walls in the second operation. After the concrete of the invert and bench walls had been poured and become thoroughly set, the last two sets of rangers and braces were removed and the concrete of the arch was then poured. The upper brace of the lowest set of sheeting was driven up enough to permit the completion of the arch without removing this brace. The 2-in. blocks shown at the ends of the braces were required because the braces were too short. This is an expedient often adopted when braces are short, and is not particularly objectionable, although it is preferable that the braces be of such a length as to avoid the use of blocks other than wedges.

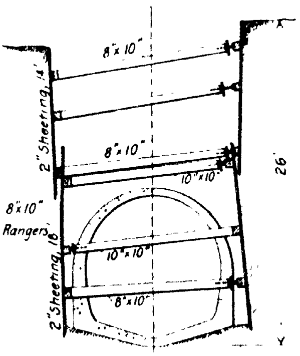


Fig. 65—Sheeting for sewer 13 ft. 3 in. by 12 ft. 11 in.

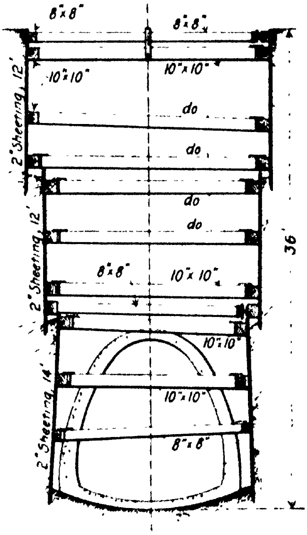


Fig. 66—Sheeting for sewer 12 ft by 12 ft

A sketch of the cross-section of a trench in which a 12 × 12-ft. semi-elliptical concrete sewer was constructed is shown in Fig. 67. There was considerable settlement of the banks and sheeting. To avoid the slipping of the rangers and braces they were tied together by cleats, as shown. The upper 10 ft. of this trench was in alluvium, below which it was in sand and gravel. Jack screws were not used upon this bracing, the struts being cut long enough to require hard driving. Better results might possibly have been obtained by wedging the braces.

In Fig. 68 is shown the cross-section of a trench in which a 12 × 12-ft.

semi-elliptical concrete sewer was constructed. This sketch shows the position of the Carson trench machine used for hoisting the excavated material from the trench. This machine was carried on tracks laid on 10 × 10-in. stringers, supported by the ground on either side of the trench. At the left of the trench machine and attached to it will be seen the frame which was used for supporting a steam plank-driving hammer and the plank-pulling apparatus. It was necessary to remove at least three sets of rangers and braces after the invert and bench walls had been placed and become thoroughly set, before the arch forms could be placed.

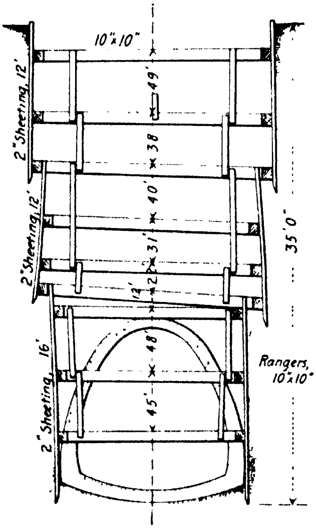


FIG. 67.—Poor sheeting for sewer 12 ft. by 12 ft.

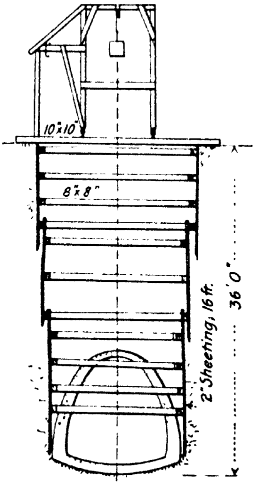


FIG. 68.—Good sheeting for sewer 12 ft. by 12 ft.

Box Sheeting.—Horizontal sheeting, sometimes called "box sheeting," is sometimes used where the material excavated is such that the banks will stand untimbered for a considerable length of time without great danger of their caving. With it less care need be taken in trimming the banks of the trench plumb than in the case of vertical sheeting, as it is not absolutely necessary, though it is preferable, that each plank be placed directly under the one above. After the excavation has been carried as deep as practicable without bracing (usually the width of three or four planks), the planks are placed along the sides of the trench and held in position by 2-in. cleats placed vertically at each end and usually in the center of the planks. These cleats are in turn tightly braced by means of ordinary wooden braces, with or without the use of wedges, or extension trench braces. As the width of the trench between the opposite planks is likely to vary, extension braces are to be preferred to the ordinary driven brace, as they are more readily adjusted and by their use the trench may be more quickly braced. The extension braces are also preferable, as there is little or no jar in connection with placing them, while if driven braces are used the jar resulting from the driving may be sufficient to endanger the banks.

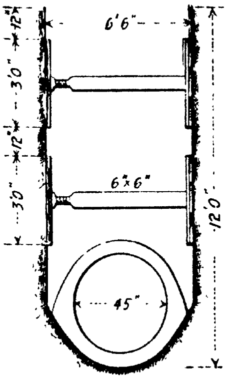


FIG. 69.—Box sheeting for 45-in. sewer

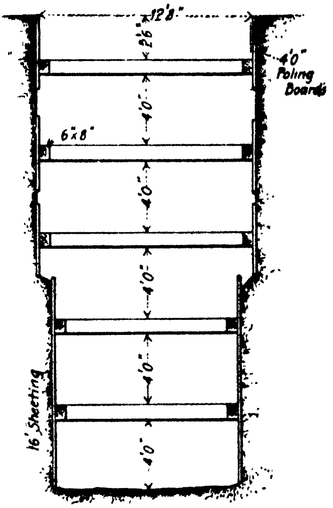


FIG. 70.—Poling boards and vertical sheeting for sewer 7 ft. 6 in. by 6 ft. 8 in

Box sheeting has been used in some cases where the material excavated was very unstable, such as coarse gravel and dry sand. In such cases the excavation can be carried only deep enough to accommodate a single plank at a time. Each set of planks is temporarily braced until the trench has been carried deep enough to accommodate uprights supporting three or four planks, after which the uprights, with one or two braces against each pair, may be substituted for the individual plank braces. In this class of material box sheeting may be more expensive and troublesome than vertical sheeting, but it is quite useful under certain difficult conditions, as for example in trenches between car tracks or under structures which interfere with the placing of vertical sheeting. The use of the wooden horses and temporary stages required by plank drivers is also avoided by the use of box sheeting, which is often advantageous, especially in narrow streets.

Sometimes the first few feet of excavation may be in dry clay, alluvium or other material which will stand fairly well, while beneath this stratum sand or gravel may be encountered. In such cases a combination of horizontal sheeting on top and vertical sheeting below, may be used with success.

Fig. 69 shows a trench about 12 ft. in depth, the banks of which were supported by two sets of box sheeting, each three planks in depth. The planks used were 2 in. thick, 12 in. wide, and 18 ft. in length. The cleats were 2 × 12 in. and 3 ft. in length. Extension braces were used, as shown in the sketch. The material excavated was a dry alluvial clay.

Poling Boards.—This method of timbering is similar to that of vertical sheeting, except that short planks 3 or 4 ft. in length called poling boards are used and the sheeting is placed against the banks from time to time as the excavating proceeds instead of being driven. The planks are placed vertically against the properly trimmed banks, and are supported by means of rangers and braces, as in the case of vertical sheeting. In some cases where the banks stand well it is possible to get along with a single set of rangers and braces for one set of poling boards, as illustrated in Fig. 70. This, however, is not as safe as the method shown in Fig. 71, where two sets of rangers and braces are used for each set of poling boards. The nature of the material in which the trench illustrated by Fig. 70 was excavated was such that a space of from 6 to 12 in. could be safely left unsupported between the bottom of one set of poling boards and the top of the set next below.

Where this method of sheeting can be used, economy in excavation will result, because the trench will be of the same width from top to bottom, regardless of depth. Thus with a trench sufficiently deep to require three sets of vertical sheeting, a saving of about 3 ft. in width at the top and about 1.5 ft. opposite the second set of sheeting, will result from the use of poling boards. Short pieces of plank which accumulate on sewer work requiring some vertical sheeting can be advantageously used for poling boards, so that a combination of poling boards and vertical sheeting often proves economical. The use of poling boards has the same advantages as the use of box sheeting, in that they do not project above the surface of the ground at any time.

The chief disadvantage in the use of poling boards lies in the fact that if there is a collapse in the timbering of any portion of the excavated section, resulting from the running out of the material behind the sheeting, serious deformation or even collapse of the entire timbering of the section may result. The danger of this is much greater with poling boards than with vertical sheeting

An illustration of sheeting by means of sets of poling boards many of which were braced by single sets of rangers and braces, is shown in Fig. 70. The upper portion of the trench, to a depth of about 18 ft., was in dry alluvial clay, the lower portion in sand. The poling boards were 4 ft. in length and were supported by 6 × 8-in. rangers and driven braces of the same dimensions. Where the lower portion of the trench is shored with vertical sheeting, it is necessary to excavate the upper portion sufficiently wide to provide for placing the vertical sheeting planks inside the upper rangers.

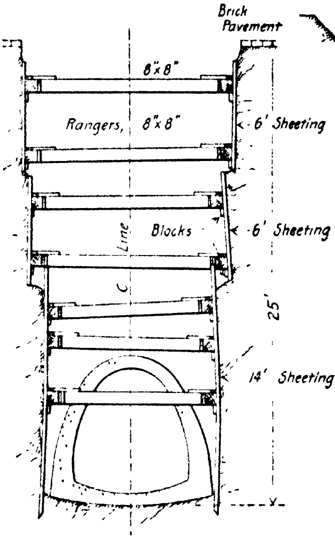


FIG. 71 —Poling boards and vertical sheeting for 7-ft sewer

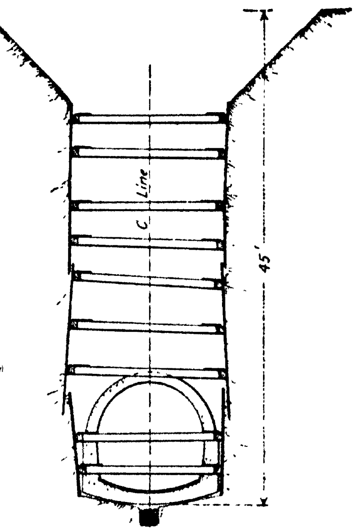


FIG 72 —Trench supported by poling boards with single sets of rangers and braces, for sewer 10 ft. 1-½-in. × 10 ft. 7 in.

Theoretically there may be some advantage in placing poling boards in a slightly inclined position, although there is more danger of the slipping of the rangers and bracing. This method is illustrated by Fig. 71. The upper portion of the trench was sheeted by means of poling boards 2 in. in thickness, each set being supported by two sets of rangers and braces. The poling boards were inclined into the trench at the top and out at the bottom and the bottom of each set was slightly behind and below the top of the next lower set. Poling boards set this way have been used with a single set of rangers and braces on the theory that the bottoms of the upper set of boards cannot be forced in while the tops of the planks below are braced against them. Fig. 72 illustrates the method of supporting the banks of a deep trench with poling boards. The upper portion of the trench was excavated to a depth of about 10 ft., the banks being sloped at an angle of about 45° and unshored. Below this to an elevation slightly below the top of the sewer, the banks of the trench were supported by means of poling boards about 4 ft. in length, each set of which was supported by a single set of rangers and braces. Below the lowest set of poling boards a set of vertical sheeting was driven and supported by two sets of rangers and cross-braces.

The material excavated from this trench was dry alluvial clay for a depth of about 16 ft. from the surface, below which dry clean sand was encountered for a depth of about 25 ft., the last 4 or 5 ft. being in water-bearing sand containing some small gravel.

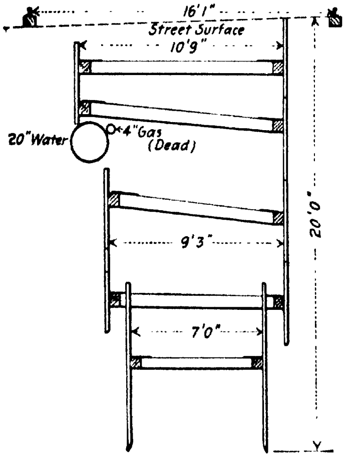


FIG. 73.—Poling boards and vertical sheeting for 4-½-ft. sewer.

Poling boards are particularly useful when it is necessary to excavate below existing structures which project into the trench, thus preventing the placing of vertical sheeting. In Fig. 73 a trench of this kind is illustrated, in which a 20-in. water pipe and a 4-in. gas pipe were encountered. The trench was opened sufficiently wide to expose these two pipes and to permit taking out the gas pipe. Below the 20-in. water pipe, although the width of the trench was decreased, the face of the bank was under the pipe so that it was not practicable to support it by means of vertical sheeting. The character of the material excavated was such that the banks would stand while the excavation was being carried down about 4 ft. When this depth was reached poling boards were placed and securely braced. The lower portion of the trench was shored by means of vertical sheeting.

Stay Bracing.—When the excavation is in hardpan, dry clay, or dry loam, it is often unnecessary to provide close sheeting, although some support for the banks may be needed. In such cases stay bracing, or skeleton sheeting, will prove economical. The simplest form of stay bracing involves the placing, at intervals of 6 to 10 ft., of pairs of vertical planks braced tightly against the banks of the trench. The braces may conveniently serve as supports for staging platforms in trenches which are sufficiently deep to require that the material be staged out.

If a trench must be left open for several days, the use of stay bracing is not to be recommended unless conditions are especially favorable, as heavy rains are likely to soften the banks and cause expensive and dangerous caving.

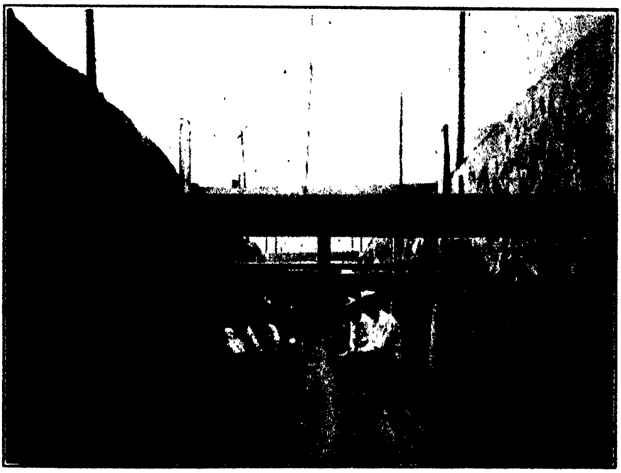


FIG. 74.—Trench in alluvium; stay bracing

Fig. 74 clearly shows the method of supporting the banks of a trench by means of stay braces. In this case, each pair of stay braces was supported by a single brace, some of which were 6 × 6-in. timbers, and others consisted of two 2 × 6-in. planks.

Skeleton Sheeting.—In some cases where it is difficult to determine prior to the completion of the excavation, whether or not it will be necessary to use vertical sheeting, skeleton sheeting is used. This consists of the usual rangers and braces with planks between the rangers and the banks of the trench opposite the braces. By putting in these frames, it is possible to slip planks in later without delay wherever found necessary. It is often desirable to place such planks at intervals of 2 or 3 ft. where it is unnecessary to provide close sheeting.

Danger Due to Previous Excavations.—When a trench is excavated through natural ground which has not before been excavated, the banks are not likely to cave until excavation has reached a depth of 3 to 5 ft. if the excavation is in loam, clay, hardpan, or other similar material. If, however, the ground has been previously excavated and refilled, or if a trench has been excavated and refilled parallel to the trench under consideration, the banks are very likely to cave in and the shoring should be placed before the trench has been carried to an unsafe depth. For this reason the excavation of trenches in the older city streets likely to have been excavated for water and gas pipes, or for conduits, is more hazardous than similar excavations in new and undeveloped territory not likely to have been disturbed by excavation. Similarly, excavation in filled land is always treacherous and requires bracing and sheeting.

Bracing Curves.—When a sewer is to be constructed around a curve, the trench is generally laid out on chords of a length dependent upon the degree of curvature. The ends of the rangers are cut on radial lines, thus making the outer rangers longer than the inner rangers. It is desirable to have the braces nearly at right angles to the rangers but where the curve is very sharp this is not always practicable. Whenever the braces are not placed substantially at right angles to the rangers, cleats or short planks should be securely spiked against the rangers on both sides of each brace to prevent it from slipping. In some cases where the banks of the trench are not very heavy, it may be possible to excavate the trench on the line of the curve and instead of heavy timbers one or two thicknesses of 2-in. planks bent to the curve may be used for rangers. In such cases it will usually be helpful to scarf with a saw the inner side of each plank at intervals of 4 to 8 in. to a depth of from 1/4 to 1/2 in. to aid it in taking the curve without cracking or breaking, the inner side referred to being the side of shorter radius of curvature.

Jetting.—Where sheeting must be driven much ahead of excavation, it is occasionally found impossible to make substantial progress in the driving of sheeting by ordinary methods. In such cases a jet of water may be forced into the soil just below the bottom of the plank so that as the soil becomes softened the plank can be driven with comparative ease.

In some cases the bottom of each plank is fitted with a special appliance by means of which the jet of water is introduced into the soil immediately below the plank. In other cases the water may be conveyed to the lower end of the sheeting by a 3/4- or 1-in. pipe, independent of the sheeting itself, and pushed down by hand. Where the planks are fitted with special jetting shoes, it is economical to drive them a considerable distance below the bottom of the trench at one operation.

The efficiency of the jetting method depends upon the resulting increase in the fluidity of the material into which the sheeting is to be driven.

Pulling Sheeting.—Pulling, or drawing, wooden sheeting is ordinarily a quick and simple matter if proper appliances are at hand. If the planks are long or if steel piles are used, steam or electric power can be advantageously utilized in pulling them. In such cases a wire cable or chain should be thrown around the planks as low down as possible and attached to the hoisting rope of the engine with which they are to be pulled. Often several planks can be drawn in this manner at one operation. Where sheeting is pulled by hand each plank is withdrawn separately, a convenient apparatus for this being a lever and plank clamp, Fig. 99, page 262. It is a U-shaped iron casting, the length of the U being about 8 in. and the width varying according to the thickness of the sheeting but usually being 2 in. To this clamp is attached an iron ring into which the hook on the end of the lever engages. As the plank is pulled a distance of about a foot, the lever is raised, the clamp slipped down and a new hold taken upon the plank.

Where it is necessary for the backfilling to be thoroughly tamped and the space occupied by the sheeting to be refilled to reduce the danger of settlement to a minimum, it may be desirable to draw the sheeting a few feet at a time as the backfilling progresses, instead of pulling it entirely out of the trench after the backfilling is completed. By the former method a better opportunity is afforded to fill completely the voids left by the withdrawal of the plank, and to ram the material thoroughly. In cases where such care is unnecessary the sheeting may be withdrawn and the voids filled with fine, relatively dry material which can be consolidated by the use of long, narrow rammers or by water. While in most cases it is practicable to withdraw the sheeting a few feet at a time, it is always inconvenient to do so and it adds somewhat to the cost of the work.

LUMBER

Kinds of Lumber.—The kinds of lumber used for shoring trenches vary in different parts of the country. In the East the use of spruce was formerly almost universal, although the scarcity and increased cost of this kind of timber in recent years have led to the more general use of long leaf yellow pine. Hemlock has been used in some communities, with some success, although it has generally been found inferior to either spruce or pine. In the Middle West and South, yellow pine is largely used, although hard wood, such as oak, is used in many places. Oregon pine is generally employed in trenches on the Pacific Coast. Ordinarily the first cost of the timber is an important if not the chief consideration. If the sheeting requires hard driving, it is advisable to get a soft tough wood or a hard strong wood. For this purpose spruce proves very satisfactory and oak will stand driving fairly well. Hemlock is likely to splinter and is not usually satisfactory where hard driving is necessary. Oak is likely to warp and prove difficult to handle on this account, and is also heavy. On the whole, spruce and yellow pine appear to be the most satisfactory kinds of lumber for the bracing and sheeting of trenches.

Planks for sheeting should not be over 10 in. in width, except notched planks, nor less than 6 in. It requires about the same amount of labor to drive a plank 4 in. wide as one 8 in. wide, but two 8 in. planks can ordinarily be driven in about the same time and perhaps with less exertion than one plank 12 in. in width. It is considered by many, especially in the eastern part of the country, that 10 in. is the most desirable width of planks for ordinary sewer sheeting, as they are not so wide as to cause difficulty in driving and there are not so many to be handled as if narrower planks are used.

Dressing Lumber.—The lumber used for sheeting and bracing trenches is generally square edged, sawed stock, although round timbers may be used for braces and rangers. Planks for poling boards and box sheeting require no dressing, although they should be of approximately uniform thickness and length. Rangers (commonly 16 ft. long) should be of uniform length so that the braces of the several sets may come directly under each other.

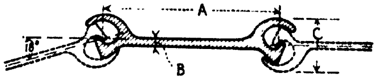
If it is practicable to saw the braces to the desired length in advance of their use, it will be found that the bracing will be done more expeditiously than if each brace is cut to measure as required, although the latter method is sometimes necessary upon heavy and difficult work. Braces should be beveled along their vertical edges, the corners about 1 in. each way being cut off. This will facilitate driving and also avoid a tendency toward splitting.

Planks for vertical sheeting are generally beveled for a distance of about 6 in. from one end. They should not be beveled to a sharp edge but the thickness should be made about 1/2 in. In some cases, especially where the planks are to be driven a considerable distance below the bottom of the excavation, as in quicksand, it may be advantageous to bevel both sides of the lower ends of the planks, thus avoiding the tendency for the planks to be forced either way from the desired line of sheeting. If there is a tendency for the planks to separate as they are driven in advance of excavation, it may in some cases be overcome by cutting the lower ends on a slant, as shown at *B* in Fig. 56. When a plank is cut in this manner the tendency is for it to be forced by the ground which it penetrates tightly against the plank previously driven adjacent to it.

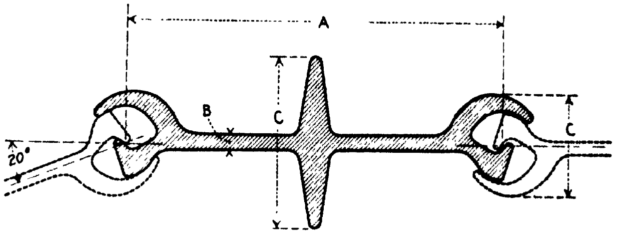
Vertical sheeting, especially where soft lumber like spruce or pine is used, should be dressed at the top to receive plank caps, which will protect the ends from brooming under the driving maul. Care should be taken to dress the planks sufficiently so that the cast-iron caps will fit loosely upon them, as a driving fit will result in cracking and breaking of the caps.

STEEL SHEET PILING

In recent years since the cost of lumber has become so high and the quantity of heavy engineering foundation work has greatly increased, steel sheet piling has come into common use, particularly upon cofferdams and foundation work near bodies of water. Several types of steel piling are shown in Figs. 75, 76, 77, 78 and 79. Thus far comparatively little sheet steel piling has been used for the curbing of or-



Type "A".



Type "B".

FIG. 75.—Lackawanna steel sheet piling.

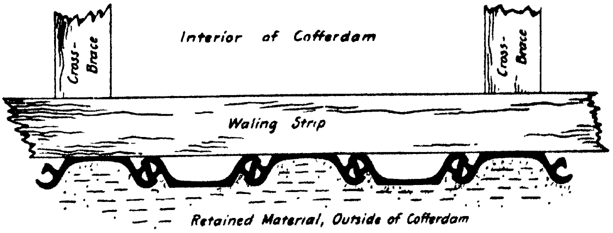


FIG. 76.—Lackawanna arched web piling

dinary sewer trenches, although there have been a number of instances in which it has been successfully used on this class of work. Steel piling is not as easily handled, driven or pulled as plank, but its life is obviously much longer, as upon ordinary work it can be used over and over again without serious depreciation.

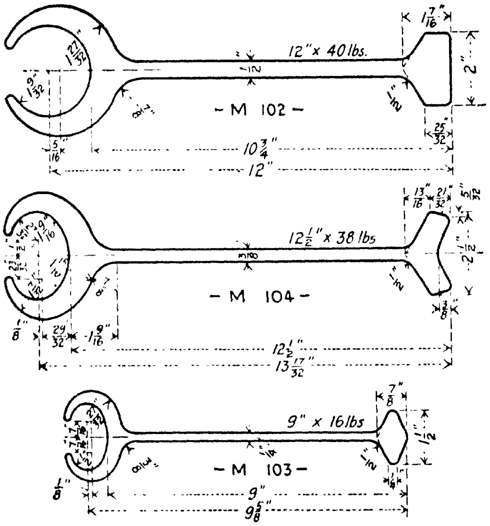


FIG. 77.—United States steel sheet piling (Carnegie Steel Co.)

The heavier types of piling must be driven with power hammers although some of the lighter types may be driven by hand. It is necessary in most cases, to withdraw the sheeting by power.

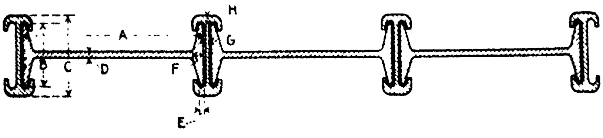


FIG. 78.—Jones & Laughlin steel sheet piling

The dimensions and weights of steel piling made by the Lackawanna Steel Co., the Carnegie Steel Co., the Jones & Laughlin Steel Co., and the Wemlinger Steel Piling Co. are given in Tables 40 to 43.

Fig. 80 illustrates the method of sheeting a trench with steel piling.

TABLE 40.—DIMENSIONS AND WEIGHTS OF STEEL SHEET PILING MADE BY LACKAWANNA STEEL CO., 1912 (FIG. 75)

Type	Center to center of jaws in inches	Thickness of web in inches	Weight per linear foot in pounds	Weight per square foot of wall in pounds	Width of joint over all in inches
	A	*B*			*C*
A	7	$\frac{1}{4}$	12.54	21.5	1 $\frac{33}{64}$
A	12$\frac{1}{4}$	$\frac{3}{8}$	37.187	35.0	3 $\frac{45}{64}$
A	12$\frac{1}{4}$	$\frac{1}{2}$	42.5	40.0	3 $\frac{45}{64}$
B	15	$\frac{1}{2}$	62.56	50.05	6 $\frac{1}{4}$

TABLE 41.—DIMENSIONS, WEIGHTS AND PHYSICAL PROPERTIES OF WEMLINGER STEEL SHEET PILING (FIG. 79)

			Sheet-piling with short clips[1]				Physical properties	
			Approximate weight[2]					
No.	Type	Thickness, inches	Per square foot of sheet piling interlocked, pounds	Per linear foot of single pile, pounds	Per clip, pounds	Maximum lengths usually furnished, feet	Least radius of gyration, inches	Section modulus of sheet piling interlocked, inches^3
1	A	$\frac{1}{16}$	5.0	5.0	0.75	12	0.68	0.69
2	A	$\frac{7}{64}$	7.5	7.5	0.80	16	0.69	0.87
3	A	$\frac{1}{8}$	8.5	8.5	1.10	16	0.69	0.97
4	B	$\frac{7}{64}$	8.0	8.0	1.55	20	0.88	1.12
5	B	$\frac{1}{8}$	9.5	9.5	2.10	24	0.88	1.25
6	B	$\frac{5}{32}$	11.5	11.5	2.15	24	0.88	1.46
7	B	$\frac{3}{16}$	13.5	13.5	2.20	24	0.88	1.68
8	C	$\frac{3}{16}$	15.0	24.0	2.45	30	1.41	3.42
9	C	$\frac{1}{4}$	19.0	30.0	3.00	40	1.41	4.65
10	C	$\frac{5}{16}$	23.5	36.0	3.50	50	1.41	5.84
			Sheet piling with full length clip					(Clip not included in computations)
11	B	$\frac{7}{64}$	10.0	10.0	Weight of clip included in figures given in two preceding columns	20	0.88	1.12
12	B	$\frac{1}{8}$	11.0	11.0		24	0.88	1.25
13	B	$\frac{5}{32}$	13.0	13.0		24	0.88	1.46
14	B	$\frac{3}{16}$	16.5	16.5		24	0.88	1.68
15	C	$\frac{3}{16}$	17.0	27.5		30	1.41	3.42
16	C	$\frac{1}{4}$	22.25	33.5		40	1.41	4.65
17	C	$\frac{5}{16}$	27.25	41.5		50	1.41	5.84
18	D	$\frac{3}{16}$	23.5	27.5		30	1.41	5.64
19	D	$\frac{1}{4}$	31.0	36.0		40	1.41	7.36
20	D	$\frac{5}{16}$	38.0	44.5		50	1.41	9.10

[1] Types A, B, and C are furnished with one, two, three, or any number of short clips, as desired.

[2] Corrugated steel sheet piling, being made from plates, is subject to a variation in weight of 2 1/2 per cent. above or below the theoretical weight, in accordance with the Manufacturers' Standard Specifications. In all cases, the weight per square foot is given for the sheet piling interlocked and, therefore, includes the overlap.

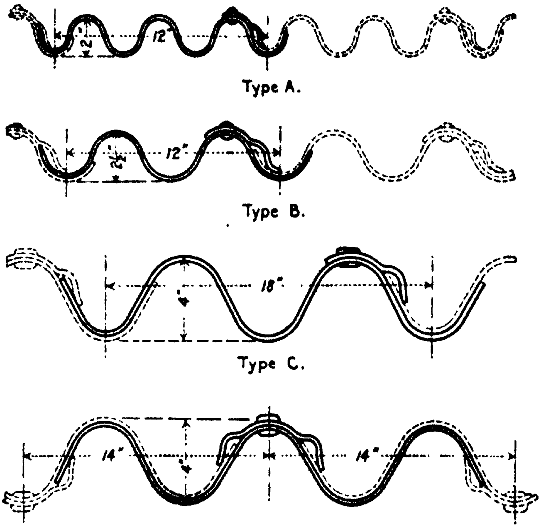
TABLE 42.—ELEMENTS OF UNITED STATES STEEL SHEET PILING OF CARNEGIE STEEL CO. (FIG. 77)

Section index	Description		Area, inches^2	Neutral axis on central line of web				Straight section, weight per square foot	Regular corner, weight per linear foot
	Width, inches	Weight, lb per lin ft		I inches^4	r inches	S inches^3	S* inches^3		
M 102	12	40	11.63	7.31	0.79	4.00	4.00	40	40
M 104	12¼	38	11.20	8.35	0.87	4.30	3.97	35	38
M 103	9	16	4.71	1.45	0.56	1.13	1.51	21	16

S* is the average section modulus per horizontal foot of wall interlocked in place.

TABLE 43.—STANDARD SHEET PILING, JONES & LAUGHLIN STEEL CO. (FIG. 78)

No.	Size, inches	Weight per square foot, pounds	A	B	C	D	E	F	G	H
1	12 × 5	35.00	12	3.94	5	0.34	0.35	0.65	0.21	0.44
2	12 × 5	36.25	12	3.97	5	0.37	0.35	0.65	0.21	0.44
3	15 × 6	37.20	15	4.75	6	0.37	0.37	0.74	0.23	0.49
4	15 × 6	39.75	15	4.81	6	0.44	0.37	0.74	0.23	0.49
5	15 × 6	42.25	15	4.87	6	0.50	0.37	0.74	0.23	0.49



Type A.

Type B.

Type C.

Type D.

Fig. 79.—Wemlinger steel sheet piling.

Fig. 80.—Steel sheet piling with timber rangers and braces.

It will be noticed that wooden waling pieces and braces were used to shore the piling and prevent the banks from caving. One of the difficulties in the use of steel sheeting is the holding of the rangers in the desired position, as there is a decided tendency for them to slip out of place because of the lack of friction between the steel and the lumber.

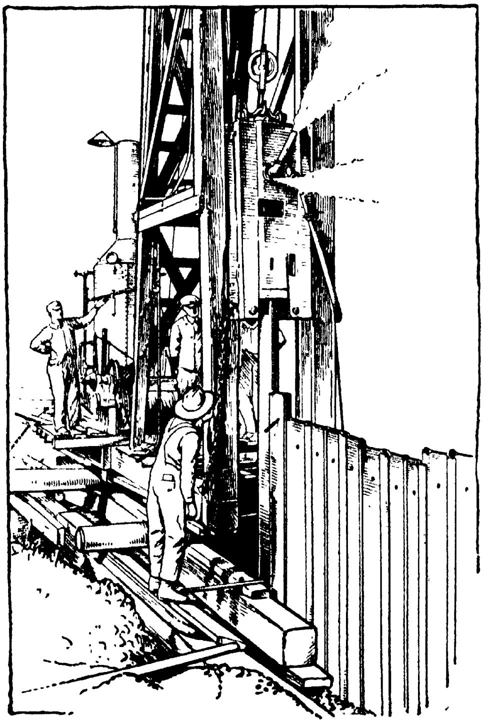
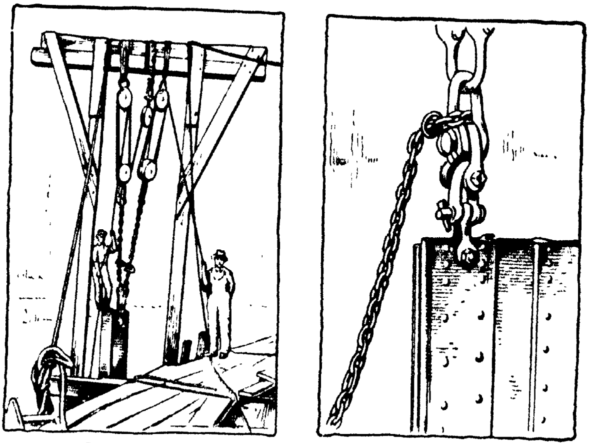


Fig. 81 —Driving steel sheet piling with steam hammer.

Fig. 81 illustrates the method of driving the sheet piling with a steam hammer. It will be noticed that there is a hole through each pile near one end into which a hook or chain can be inserted for the purpose of pulling it out of the ground at the end of the work.

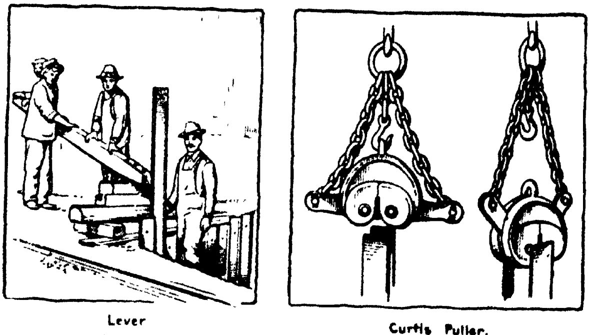
Various devices have been used to facilitate the pulling of steel sheet piling. Several of these are illustrated in Figs. 82 and 83, from "Steel Sheet Piling" by Carnegie Steel Company.

Ordinary pile drivers are used with much of the steel sheeting sunk today but there are on the market a number of steam operated hammers which have been successfully used for the purpose. Several of these hammers are illustrated in Fig. 84. Table 44 gives the weights and dimensions of the Warrington steam hammers, made by the Vulcan Iron Works, and of the sizes of piling and sheeting for which they may be safely used. The larger sizes were developed primarily for pile driving, but are sometimes required for steel sheet piling. For example the No. 1 size was used by W. A. Fargo in driving 30-ft. piles through sand



Frame and Tackle

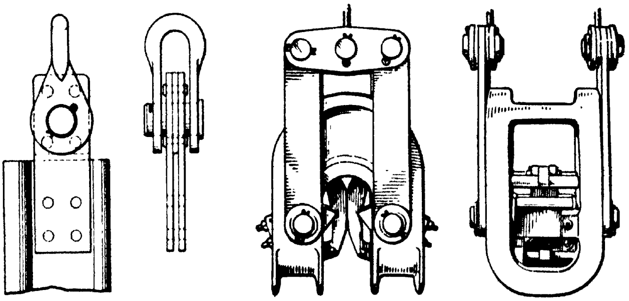
Derrick Block and Tackle



Lever

Curtis Puller.

FIG 82 —Devices for pulling steel sheet piling



Pile Pulling Clamp. Grady Pile Puller.

Fig. 83.—Clamps for pulling steel sheet piling

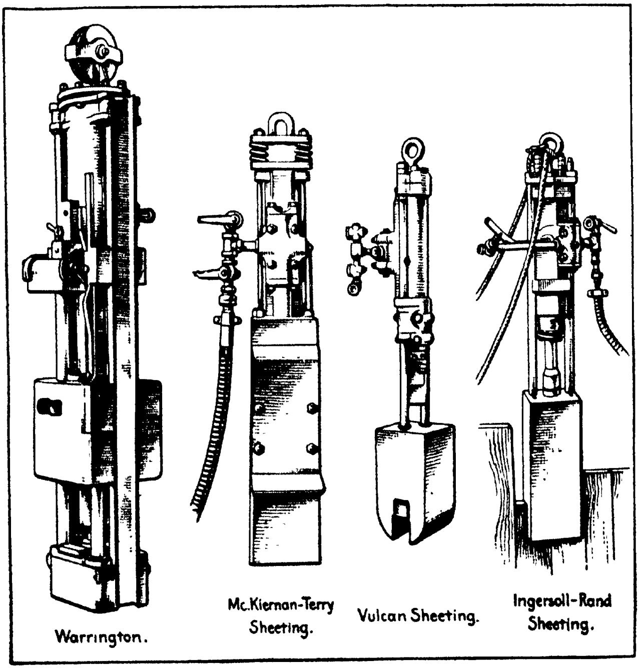

Warrington.
McKiernan-Terry Sheeting.
Vulcan Sheeting.
Ingersoll-Rand Sheeting.

Fig. 84.—Steam hammers for driving piles, steel sheet piling or plank sheeting.

and gravel, using a cast-iron follower on the top of the pile, then a wood block about 20 in. long and 15 in. in diameter and then a 1-3/8-in. circular steel plate 13 in. in diameter.

TABLE 44.—WEIGHTS AND DIMENSIONS OF WARRINGTON STEAM PILE HAMMERS (VULCAN IRON WORKS)

Size No	Total net weight, pounds	Weight of ram, lb	Dimensions cylinder, over all					Strokes per min	Steam-boiler, H P required	Size of hose, inches	Distance between jaws, inches	Width of jaws, in.	Duty, size of piles or piling hammer will drive
			Height, in	Width, in	Depth, in	Diam, in	Stroke, in						
0	16,000	7,500	180			16¼	48	60	60	2½	26	9¼	Heavy concrete piles
1	9,850	5,000	144			13¼	42	70	40	2	20	8¼	18 in sq or rd piles
2	6,500	3,000	138			10¼	36	70	25	1½	19	7¼	14 in sq or rd piles
3	3,800	1,800	96			8	30	80	18	1¼	18	6¼	10 in sq or rd piles
4	1,350	550	84			4	24	80	8	1	14	4¼	4 in × 12 in. sheeting
5	800		68	10	10	4	7½	300	10	1	.	.	3 in × 12 in sheeting

TIMBERING TUNNELS

In some kinds of material as, for example, hardpan, it is possible to excavate a tunnel drift for some distance without the use of shoring, in others as, for example, loose gravel, it is absolutely necessary to drive sheeting in advance of the excavation in order to prevent the sand and stone from rolling into the heading.

The material immediately overlying the tunnel is free to fall into it, but the arching action of the earth above prevents the sliding of a large prism of earth extending from the tunnel to the surface of the ground, as might be the case if the material were without friction and there were no arching effect. Even where a tunnel is driven through relatively loose gravel, which runs badly, it is not common to encounter excessive pressures, though the gradual running of the gravel may cause a movement of the material all the way to the surface of the ground. On the other hand, where the tunnel is driven through fine sand containing considerable water, or through a wet clay, perhaps containing some sand, the pressures exerted upon the tunnel shoring are often very great and may even approximate hydrostatic pressures.

As in the bracing of trenches, it is of the utmost importance to prevent the movement of the material immediately outside the tunnel. To accomplish this it is necessary for the timbering to follow the excavation closely, and in materials which are likely to run, the planking should be driven slightly ahead of the excavation.

Most tunnels in rock require little or no timbering. In some cases, however, where the rock is rotten or where there are seams of clay between strata of rock, it may be necessary to put in struts to prevent the rock from slipping into the excavation and it may even be necessary to sheet a tunnel if the rock is badly disintegrated.

Great difficulty is encountered in sheeting tunnels driven in rock so overlaid with soil that the upper portion of the tunnel is in earth. In such cases the upper part of the drift is first carried forward in the earth and securely timbered, after which the rock is drilled and blown. Great care is required in this latter operation to prevent blowing out braces and sheeting. Some of the difficulties encountered in this class of work are illustrated in Fig. 85.

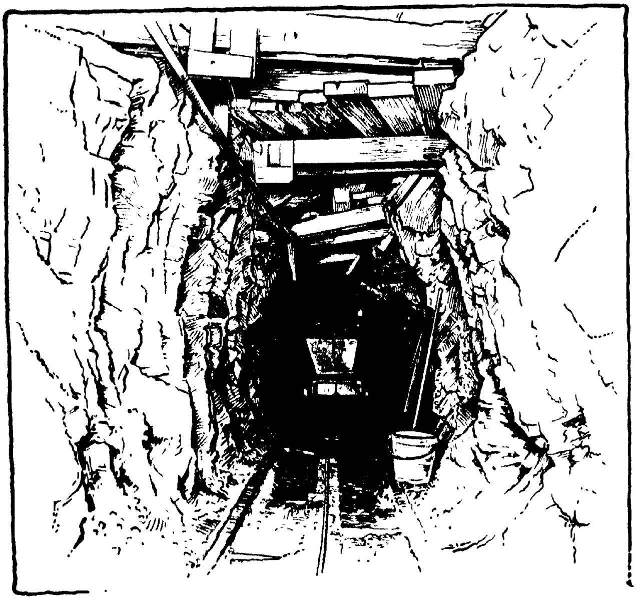


FIG. 85.—Worcester sewer tunnel in rock with roof in earth.

In hardpan it is usually possible to excavate with safety a drift 5 or 6 ft. long before timbering is placed. In some cases the masonry may be immediately built and thus the necessity of timbering the drift may be avoided. If, however, a tunnel even in hardpan is to stand some time before the masonry is constructed, it will be wise to provide a timber lining. Such a tunnel lined with poling boards, held in place by caps and legs, is shown in Fig. 86. Poling boards in a tunnel are horizontal while in a trench they are vertical.

This tunnel was driven in sections about 6 or 8 ft. in length without the use of shoring. After a section had been completed the caps and legs, which were of 6 × 6-in. spruce timber and 2 ft. 6 in. center to center, were placed in position and short poling boards slipped in behind the legs and over the caps. The caps and legs were so placed that it was necessary to drive the poling boards slightly to force them into their proper positions, thus providing a firm support for the soil outside the sheeting. The legs were supported on footing blocks and were braced across the top by 2-in. plank, spiked to the underside of the cap pieces. This tunnel stood for several months before the masonry lining was constructed and showed no signs of excessive pressure. It was about 6 ft. high and 6 ft. wide at the bottom and about 4 ft. wide at the top. Such tunnels are sometimes timbered by placing caps and legs closely together, thus avoiding the use of poling boards or sheeting.

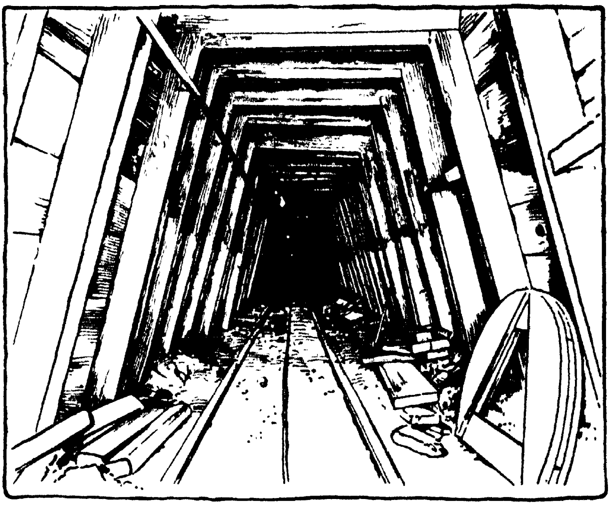


FIG. 86—Timbering in a Worcester sewer tunnel in hardpan.

In dry clay it is usually possible to drive tunnels in advance of shoring, as in hardpan, but if the clay is moist, and especially if it contains veins of water-bearing sand, the pressures exerted are likely to be heavy and to follow very quickly after the drift is excavated. The shoring of a tunnel in such clay soils should be strong and tightly wedged in order that the drift may hold its shape and position when the pressures become fully developed, and it is generally necessary to drive close sheeting about the legs and caps. The work should be performed as rapidly as possible because the continual working of the clay under the feet of the laborers causes it to assume a semi-fluid condition, which makes it very difficult to so place and support the legs that they will withstand the pressures put upon them. Where the material is bad, it may be helpful to provide a plank flooring upon which the laborers can walk and thus prevent the constant working or kneading of the clay. The legs should be supported on ample footing blocks, or stringers running entirely across the heading, and in some cases must be sunk into holes a foot or more below the bottom of the tunnel in order to provide a soil footing sufficiently hard to withstand the pressure. While these precautions are all important, the secret of success in driving small tunnels in material of this kind lies in rapid excavation and, if possible, in prompt lining of the tunnel so that the work may be completed before the material has reached the semi-fluid condition alluded to.

Timbering Tunnels in Gravel and Sand.—In gravel and sand it is necessary to drive the sheeting as fast as the excavation is made and in some cases it should be driven ahead of the excavation. A type of timbering often used in small tunnels in such ground is described in an article (*Jour. Assoc. Eng. Socs.*, 1905) written by Rufus K. Porter, at that time Assistant Engineer in the city of Newton, Mass. This type of timbering is illustrated by Fig. 87 (made up from Mr. Porter's article) and Fig. 88 (Supt. of Sewers Rpt., Worcester, Mass., 1899).

Ordinarily the first step in driving a tunnel of this kind is to put down a well-sheeted shaft. After this has been done, the method of procedure at Newton may be followed. Two lines of holes, about 18 in. apart and covering a space as long as the cap piece, were bored through the planks; each plank was then chiseled out and a 1-in. board set in behind it and secured by wedges to prevent the face of the bank from caving in, as illustrated in *a*, Fig. 87. The first frame, consisting of a cap and two legs, securely cleated, as shown in *b*, Fig. 87, was then set in place adjacent to but not quite touching the sheeting. The roof lagging pieces were then set up, the front ends resting upon the cap and the rear ends upon a temporary support, the center passing under and being wedged down from a heavy timber running across the shaft, which in turn was braced down from the rangers as illustrated by *c*, Fig. 87. The breast boards, shown in *a*, were then dropped about 2 in. and the roof lagging was driven into the loose dirt behind the sheeting. After the roof lagging had been driven far enough to prevent the material from running from behind the sheeting, the breast boards were removed and the soil behind them was allowed to run into the shaft until it had assumed its natural slope.

The upper side lagging pieces, one on each side, were then entered,

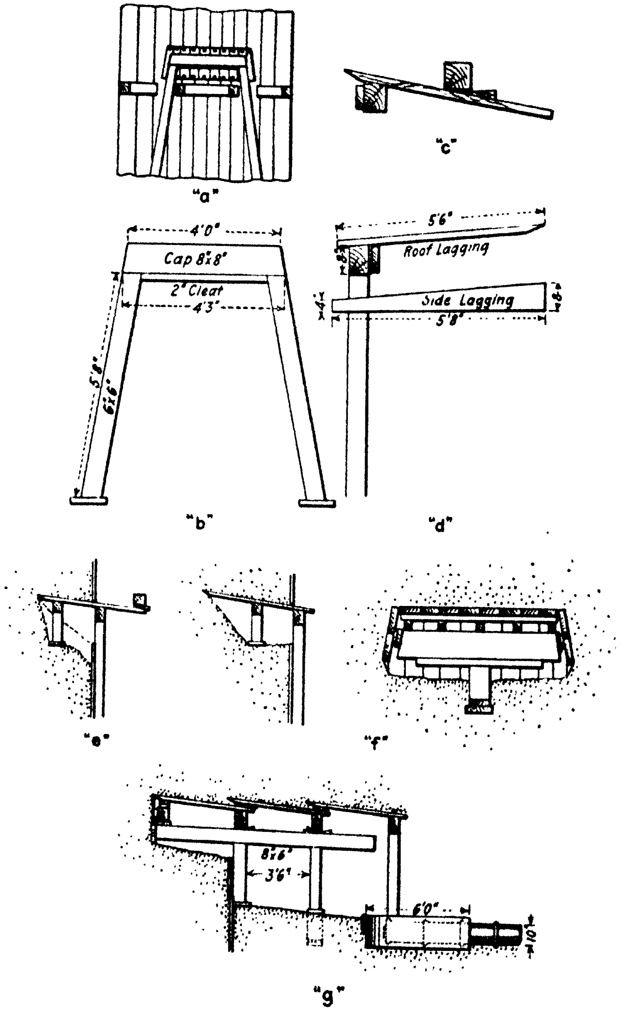


FIG. 87.—Method of timbering tunnel through fine, wet sand, Newton, Mass.

being wedged in the same manner as the roof plank. As the roof was given a pitch of 1-1/2 in. to the foot, the upper side lagging piece on each side was so tapered that its under side would be level when in its proper position, as illustrated in *d*, Fig. 87. Where the material was very wet and troublesome, several of the side planks were so tapered as to give the sides a distinct downward inclination.

After the roof lagging had been driven in about 3 ft. the sand was partially excavated and a temporary cap or "horse-head" was set up, as in *e*, Fig. 87, to prevent the plank from crowding down. The dotted line in *e* shows the extent to which the sand was excavated before this horse-head was inserted. The horse-head was placed by first removing the dirt immediately under the roof and forcing the cap piece tightly against the under side of the roof plank, after which a trench was cut in the center of the heading and a short temporary leg and prop placed under the cap piece. As the excavation proceeded the side legs were set in place and tightened with wedges.

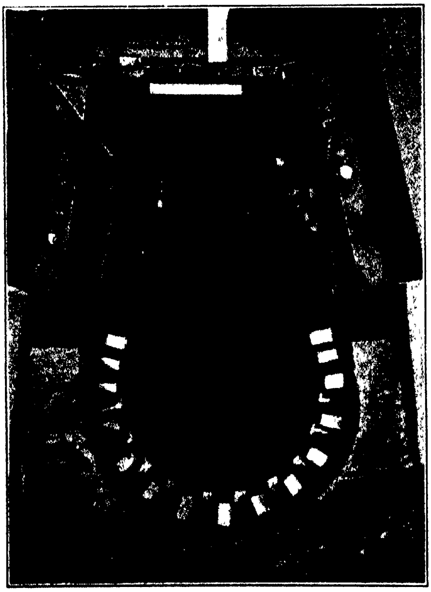


Fig. 88.—Timbering in tunnel through soft ground, Worcester.

After the horse-head had been set and thoroughly wedged against the roof, the lagging was driven to its full length, as shown in *f*, Fig. 87, which also gives an idea of the extent of excavation up to this time. The ground was then carefully cut away under one roof plank at a time and an 18-in. breast board was set up vertically under its forward end to hold the earth from running into the heading. These boards were generally set on a footing plank and secured at the top by wedges, thus helping to support the roof.

The next cap was then placed against the breast boards, on top of which were placed "chocking blocks," 7 in. long, 2 in. wide and 3 in. thick. On top of these blocks was set a waling board 2 in. thick and of the same length as the cap.

After this cap piece had been adjusted, the two upper side lagging pieces on each side were driven in flush with the breast and wedged against the cap, thus securing them firmly in place. A temporary center prop was next inserted under the cap, a narrow trench being excavated for that purpose. The prop was then wedged tightly against the cap piece which in turn raised the waling board so that it bore tightly against the roof and supported it so that the temporary horse-head could be taken out when it interfered with the work. Two timbers about 10 ft. long, called "the bars," were then placed with their ends under the cap butting against the breast boards just placed. These timbers rested on legs having a solid foundation previously prepared, *g*, Fig. 87, the back ends passing under and being wedged down from the cap pieces behind. The center prop was then removed, the roof being supported by the bars, and the whole width of the breast was cut down at once. As the material was too wet to stand with a vertical face for more than about 2 min., the excavation had to be done very quickly. The work was begun at the top and the material removed for a depth equal to the width of a bulkhead plank, which was inserted as soon as the excavation had been completed.

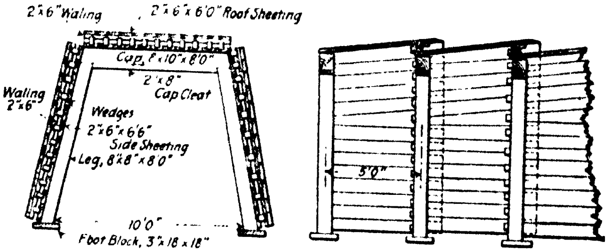


FIG 89.—Timbering in a Louisville sewer tunnel.

As it was unsafe to rely upon the bars for the support of the roof for a very long time, center props were placed as soon as possible. When the material had been excavated as far forward as the sheeting would permit, the process described was repeated.

In Louisville, Ky., 1909, under the immediate supervision of Howard S. Morse, Resident Engineer, a portion of the Beargrass intercepter, 5 ft. 2 in. by 4 ft. 11 in. in size, was built in tunnel driven through fine, dry sand. The method of timbering this tunnel and the dimensions of the timbers are shown in Fig. 89.

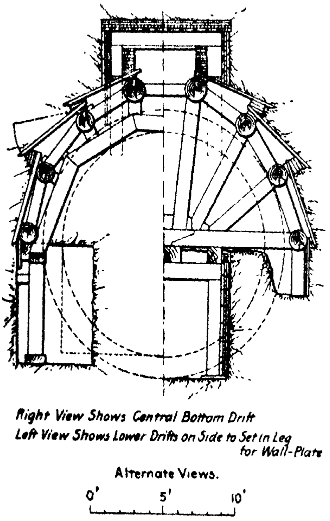

Right View Shows Central Bottom Drift
Left View Shows Lower Drifts on Side to Set in Leg for Wall-Plate
Alternate Views.
0' 5' 10'

FIG. 90.—Typical crown-bar system of timbering for large tunnels.

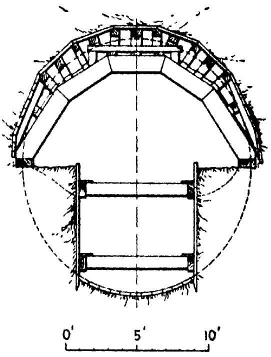


FIG. 91.—Typical arch-timber system of timbering for large tunnels.

Timbering Large Tunnels.—The timbering required to support the earth about large tunnels is frequently quite complicated. In some cases small pilot drifts are carried ahead of the main portion of the tunnel and the timbering started from these is carried around the tunnel until the entire excavation is made. In other cases, pilot tunnels are driven at the sides or in the center of the bottom of the tunnel and from these the timbering is gradually worked out until the entire section has been excavated and timbered. Several interesting types of timbering for large tunnels and subway excavations are given by J. C. Meem (Trans. Am. Soc. C. E., vol. lx, p. 20) from which Fig. 90 is taken as illustrating one such method. This is that known as the "crown-bar" system, in which "it is customary to drive the bottom drift ahead of all,

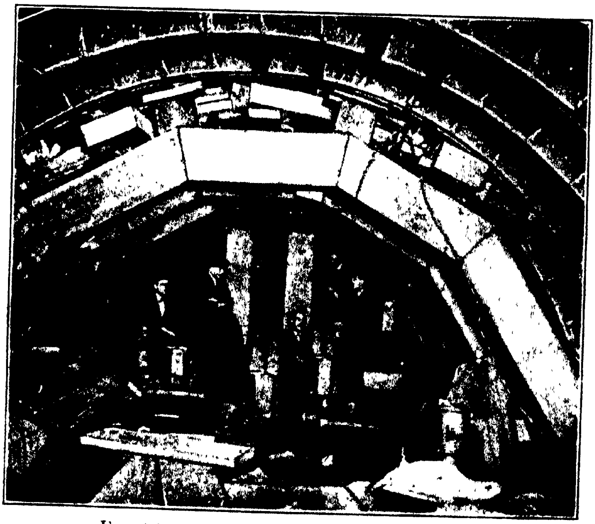


FIG 92 —Arch timbers supporting tunnel roof

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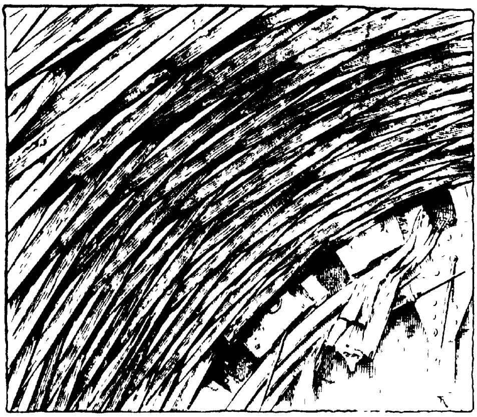


Outer wooden lining to carry thrust of shield jacks.

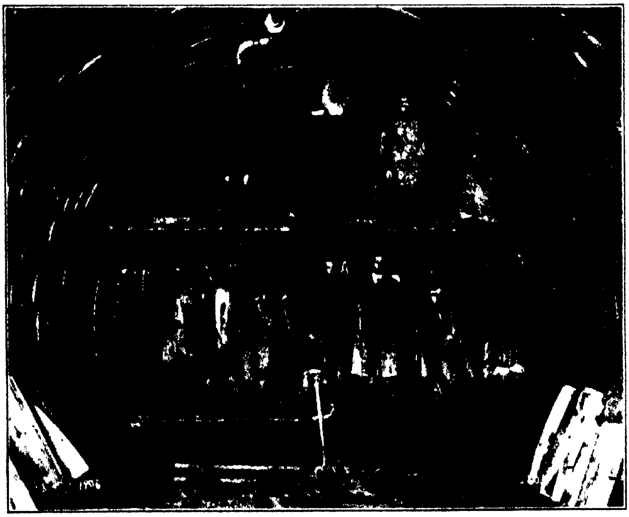


FIG 93 —Interior of Lawrence Ave tunnel, showing shield and outer wooden lining.

other work and follow this closely with a top drift. The bars are placed in position in this top drift, the poling boards are driven off approximately as shown, and the bracing is erected as the excavation proceeds. Where this type of bracing is used in rock tunnels it is, of course, unnecessary to drive a bottom drift, and the arch timber bracing shown on the left is usually put in underneath the bars as soon as the depth of excavation corresponding to the springing line of the structure has been reached. It is thus seen, Fig. 90, that, for the bar system alone, a circular tunnel of the size shown by the outer ring could be constructed, whereas with the arch timber bracing remaining in place, a tunnel no larger than that shown by the inner ring could be built."

The author points out the impracticability of filling voids over the masonry when this type of timbering is adopted and the danger of settlement due to the fact that the poling boards do not finally rest in the plane at which they were started.

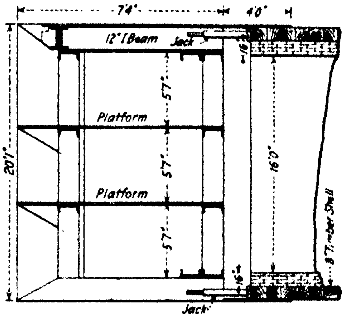


FIG 94 – Section of tunnel shield and lining, Lawrence Avenue, Chicago.

Another system of timbering used by Mr. Meem is shown in Fig. 91 and Fig. 92 (Trans. Am. Soc. C. E., vol. lx, p. 22). In this case all of the timbering except the sheeting was removed, the latter bearing directly on the brick-work.

"In this type the arch timbers were underpinned from the masonry which was put in in a centrally sheeted and braced trench, as shown, the entire masonry of the structure being built in three successive stages, of which the first is that noted in the bottom of the trench. In this method the outward thrust of the bottom legs of the arch, or segmental timbers, precludes almost entirely the possibility of any settlement while the sheeting for the middle trench is being driven. In dry ground there is practically no danger of any settlement to be caused from this method of underpinning, and the writer has supervised tunnels built safely by this method, where the ground-water level was normally 5 ft. above the subgrade and had to be kept down by constant and heavy pumping through sand."

Tunneling with Aid of Shield.—A number of large tunnels through gravel and quicksand have been driven with the aid of strong metal shields forced forward by jacks into the soil from time to time as desired, as illustrated by Fig. 93 and Fig. 94.

In some cases the shield is followed up immediately with the masonry lining of the tunnel, a thin steel tail-plate serving to prevent the settlement of the soil between the rear end of the shield and the front end of the masonry.

Fig. 95.—Wooden lining rings and bulkhead of pneumatic tunnel 6 ft. in diameter, Worcester, Mass.

In other cases the tunnel has been lined with cast iron segments as the shield was moved forward, the masonry lining being inserted within the cast iron lining at a later date.

In the case of the Lawrence Avenue Sewer, Chicago, the tunnel was lined with 8 × 8 in. timber against which the shield jacks reacted, Fig. 93. The masonry was laid inside the timber lining.

Tunneling with Compressed Air.—In subaqueous tunnels and sometimes in tunnels through very treacherous quicksands located in

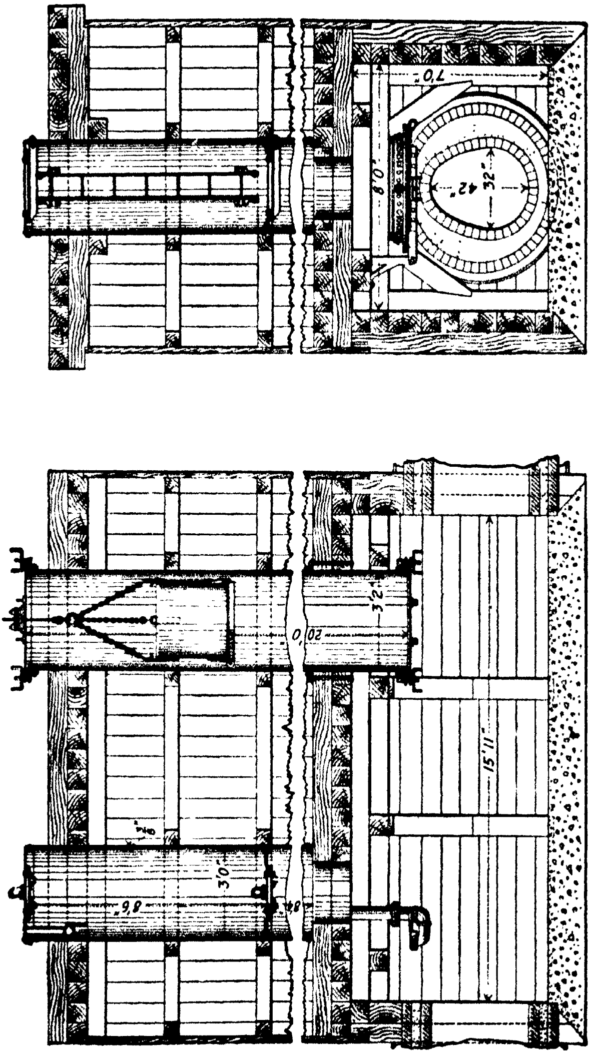


FIG. 96.—Section through caisson and air locks, Worcester sewer tunnel.

close proximity to buildings, it has been found necessary to apply air pressure to the tunnel to prevent the inflow of water and earth. Such tunnels have been shored by means of cast-iron segmental plates, and in some cases by wooden segments, as illustrated in Fig. 95. (Rept. Supt. of Sewers, Worcester, 1899.)

The tunnel was 6 ft. in diameter, and "the temporary lining, put in as fast as material was excavated, consisted of wooden rings 18 in. long. These rings were cut into eight segments, and as the segments had to be put in place from the inside, one piece was cut so as to form a key, wedging as driven into position from the inside, and the segments each side of it were cut to fit this key. All other pieces were cut on the radial lines. The segments were framed of 2 × 3-in. North Carolina pine, being pinned together by 1/4-in. carriage bolts. The ribs of the rings were cut on the circle, 6 ft. in diameter on the outside. These segmental frames were covered with 3/4-in. matched spruce sheathing, which was stuck curved on one side to rest tightly on the curved frame. The frames were bored by template, so that there was no delay in bolting them together when in place. Three 1/2-in. bolts were used on each side and two of the same size on each end."

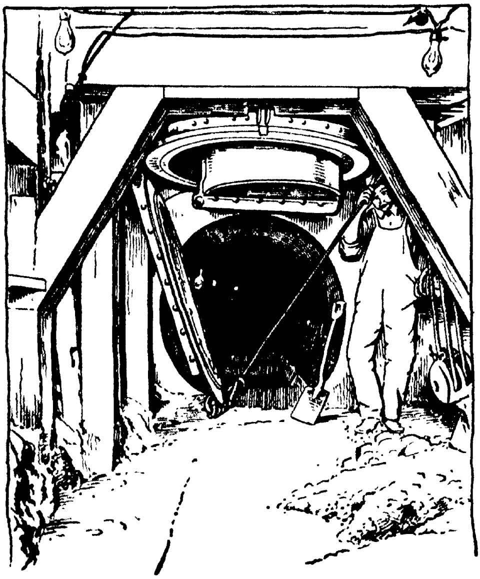


FIG. 97.—Working chamber of caisson; bucket is ascending through lock and lower door is being closed.

This tunnel was entered through a caisson 8 ft. wide, 16 ft. long and 7 ft. high, built on the surface of the ground of 8 × 8 in. spruce timbers, one course running horizontally and the other vertically. After this caisson was built the earth was excavated from below it and it was gradually forced down into place. The caisson with the bucket and man locks is illustrated in Figs. 96 and 97.

The use of cast iron rings made up of short segments is shown in Fig. 98, which was prepared from a photograph taken in the southern low level sewer of the Main Drainage Works of London. This sewer was built in tunnel with the aid of compressed air and the illustration is typical of much of the tunneling which has been done through bad ground in the vicinity of London, England. ("Main Drainage of London," by Sir Maurice Fitzmaurice.)

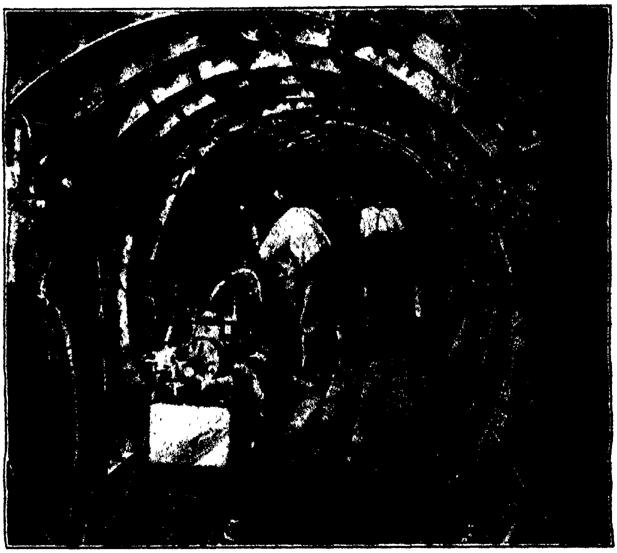


FIG. 98.—Cast iron lining segments, southern low-level sewer No. 2, Camberwell, London main drainage.

TOOLS REQUIRED

While sheeting and bracing may be done with tools found upon most kinds of construction work, it is desirable and economical to provide a few specially designed implements. A cross cut saw will be found advantageous for cutting up lumber, and an adz should be provided for dressing it. Vertical sheeting can be conveniently driven with a wooden maul, or beetle, made of a tough hard wood, such as elm, and weighing about 25 lb. Such a maul should be provided with iron rings set back from the faces of the hammer and securely wedged and pinned to it. For the handle of a maul a pick handle or hammer handle is preferable to a round handle as there is less tendency for the maul to turn in the hands of the driver, resulting in striking an uneven or glancing blow.

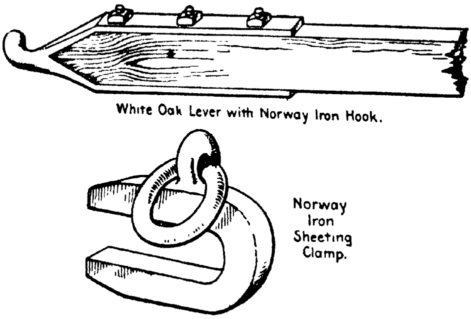
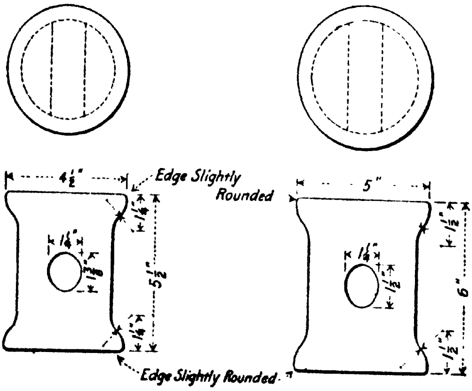

White Oak Lever with Norway Iron Hook.
Norway Iron Sheeting Clamp.

Fig. 99.—Sheeting or plank clamp and lever.



16 Pounds. 23 Pounds.

Fig. 100.—Large and small bracing hammers.

A cast-iron plank cap should be provided for the protection of the ends of the planks or in hard driving they may become so splintered and broomed that they can be used but once; in fact, they may sometimes be so damaged in this way that they cannot be driven to the required grade. Upon very light and easy work it may not be always necessary to use plank caps, but they should always be at hand. Such caps should be made to fit the prevailing width of planks which, where practicable, should be about 10 in.

For driving braces it will be found convenient to provide special bracing hammers, Fig. 100, weighing about 16 lb. These hammers are so designed that the blow can be delivered close to the end of the braces and they are much more effective than an ordinary sledge hammer. A hammer of less than 16 lb. weight is not desirable for bracing and it has been found that one weighing more than 16 lb. is rather clumsy for work in ordinary trenches, although for heavy bracing a hammer weighing about 23 lb. is frequently used.

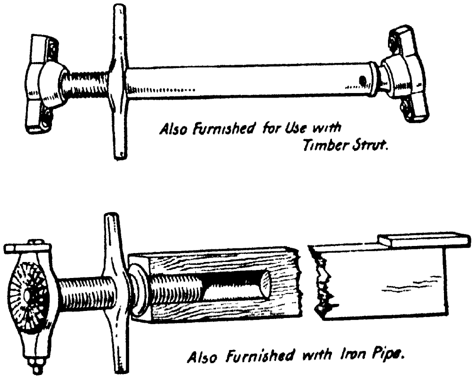

Also Furnished for Use with Timber Strut.
Also Furnished with Iron Pipe.

Fig 101.—Extensible trench braces.

In recent years metal extensible braces, Fig. 101, have often been substituted upon much light trench work for the wooden braces formerly generally used. These braces are more quickly applied than the timber struts and require no driving, an advantage where the banks are unstable and likely to cave if jarred. These braces may be provided with lugs on both ends, which overhang the rangers and prevent them from falling, with danger of injuring the laborers working below, in case the bank yields enough to loosen them.

This type of brace is usually fitted with lap-welded wrought iron pipe and the length of brace may be varied by substituting different lengths of pipe. It is customary, however, in departments having trench work in hand at all times, to carry in stock a supply of braces of several lengths to avoid the necessity of changing the pipes.

The dimensions of extensible trench braces which can usually be obtained from stock are given in Table 45.

TABLE 45.—DIMENSIONS OF EXTENSIBLE SEWER BRACES

(Harold L. Bond Co., Boston)

Length of brace closed	Length of screw	Diameter of screw	Will spread
18 inches	12 inches	1½ inches	8 inches
21 inches	12 inches	1½ inches	8 inches
24 inches	12 inches	1½ inches	8 inches
27 inches	12 inches	1½ inches	8 inches
30 inches	12 inches	1½ inches	8 inches
36 inches	12 inches	1½ inches	8 inches
42 inches	14 inches	1½ inches	10 inches
48 inches	14 inches	1½ inches	10 inches
54 inches	16 inches	1½ inches	12 inches
60 inches	16 inches	1½ inches	12 inches
66 inches	18 inches	1½ inches	12 inches
72 inches	18 inches	1½ inches	12 inches
60 inches	18 inches	1¾ inches	12 inches
66 inches	18 inches	1¾ inches	12 inches
72 inches	18 inches	1¾ inches	12 inches
84 inches	18 inches	1¾ inches	12 inches

Such braces are sometimes provided with fixed or ball joint shoes. Those with the ball joint shoes, however, are not as convenient to handle and place as those with fixed shoes. It has also been found that there is considerable breakage of ball joint braces on account of the failure of the ball and socket joints, which are not usually machined, to seat properly.

It is desirable in some cases to use timber braces with screws on one end. In such cases one end of each brace is bored out to receive the screw, as illustrated in Fig. 101. Such braces are particularly useful upon wide trenches as they are quickly adjusted and require no driving. For wide trenches and heavy banks, many sewer builders prefer to use timber braces and wedge them against the rangers with hardwood wedges driven to refusal.

PRACTICAL SUGGESTIONS ON TIMBERING

Good workmanship is essential to the successful timbering of trenches. If it is desired to practise strict economy, it is wiser to adopt a less expensive method and to do the work in a first class manner than to adopt a more expensive method and resort to careless workmanship.

The banks should be carefully trimmed to a plane surface before placing the sheeting. As the trench is deepened the material of the bank should not be permitted to run out or ravel or be trimmed back to allow the sheeting, when driven down, to slip over it without friction, inasmuch as this practice, particularly in running sand or gravel, is likely to lead the workmen to carelessness in allowing the formation of pockets behind the sheeting. Such pockets are undesirable not only because they may result in serious settlement of the ground and increase in pressure upon the bracing, but because they are likely to result in deformation of the finished sewer by spreading of the arch when the trench is backfilled.

In excavating a trench in loose material, hay or meadow grass will be found useful to prevent the material from running through the cracks in the sheeting.

The banks of a trench should never be allowed to move, if it is possible to prevent movement. The sheeting and bracing should be placed in the trench as soon as practicable, in order to prevent any movement of the top layers of the soil. The sheeting should be driven as fast as the excavation proceeds and in quicksand it is, of course, necessary to drive the sheeting in advance of the excavation. Great care should be taken to prevent the banks from raveling where notches or "windows" are required. The pressures exerted upon timbering increase greatly as the soil back of the sheeting becomes cracked, loosened, or in any way shifts its position. Such movements of the banks are likely to cause the breakage of adjacent water pipes and sewers, resulting in the partial or complete saturation of the soil with the water leaking from them, and producing pressures approaching hydrostatic pressure.

Braces should always be tight. Where they are short and of wood they may be cut to correct length, and driven, but where they are long they should be tightened by hard wood wedges driven to refusal. Upon the lighter work extensible screw braces will be found more convenient than wooden braces.

Except upon very heavy and expensive work it will generally be found more convenient to use rangers and braces of the same size from the top to the bottom of the excavation, than to attempt to vary their size in accordance with theory. If, as is frequently the case, it seems desirable to increase the strength of the timbering toward the bottom of the excavation, or at any other point, this can be done by decreasing the space between the rangers, and adding braces.

Trenches should always be braced in such a manner as to give as much room as is possible for working between the rangers and between the braces. For this reason, as well as to reduce the quantity of excavation, it is common practice to use rectangular rangers on edge or with the long side vertical. While this is not the most economical method of utilizing the strength of the timber, it does save room within the trench and makes it possible to construct the trench slightly narrower than if the rangers were turned so that the long side would be horizontal. Moreover, this method gives greater bearing area for the braces, and, as shown in the next chapter, this transverse crushing strength may control the section.

It is generally desirable to use two braces at the contiguous ends of two sets of rangers, so that each set may act independently of the other and a settlement of one section of bracing will not affect the adjacent set. Center braces should generally be of the same size as the rangers. End braces should be of the same depth as the rangers but may generally be somewhat narrower, because the loads put upon them are smaller than those put upon the center braces.

All braces should be securely cleated to the adjacent rangers so that they will not fall to the bottom of the trench in case the banks yield and they become loosened.

CHAPTER X

SIZES OF SHEETING, RANGERS AND BRACES

Behavior of Different Materials with Respect to the Need of Shoring.—The necessity for shoring and the methods of timbering or sheeting trenches vary according to the character of soil encountered, the proximity of pavements, pipe lines, buildings and other structures likely to be damaged by settlement of the adjacent ground, and the manner in which the earth is to be excavated.

In many cases in hardpan, little or no shoring may be required in trenches carried to a considerable depth. Where it is felt that there may be some danger, an occasional stay brace, or skeleton sheeting, may be used. Hardpan usually caves in large masses and does not ravel through small openings, so that in many cases the alternate planks may be left out.

In trenches in clay, it is usually necessary to provide close sheeting and heavy timbers, for while clay stands fairly well for a time after it is first excavated, it is likely to swell and in many cases water will gradually seep toward the trench, making the clay a treacherous material and one which may impose heavy loads upon the timbering.

In dry alluvium, sheeting will generally be required, although the banks usually stand well for a time. In some cases it may be possible to leave spaces between the planks, as this material is not likely to ravel.

In trenches in gravel, close sheeting is almost always required, because of the tendency of this material to ravel and roll through small openings. It is not usually possible to excavate trenches more than 3 or 4 ft. deep in gravel, before putting in the sheeting.

Sand acts differently in different cases, depending largely upon its size and uniformity and the amount of moisture which it contains. As a rule, it is necessary to close-sheet trenches in sand, and it is not generally wise to carry the excavation more than 3 to 5 ft. deep before placing the shoring.

Where the sand is very fine and contains considerable water, high pressures are likely to be exerted upon the shoring. In some cases these pressures may approach, and perhaps even somewhat exceed, a corresponding hydrostatic pressure. In such materials the sheeting must be close and strongly braced, and the planks must usually be driven a considerable distance below the bottom of the trench to help hold them in their proper position below the lowest ranger, and to prevent the sand in the trench from being forced up by the pressure of the soil outside the sheeting.

Trenches in rock may sometimes be safely excavated without shoring. They may be treacherous, however, when the rock is seamy and when the seams lie at an angle of more than 30° with the horizon, and more especially where these seams are filled with clay or other material upon which the rock may readily slide. It is often difficult to determine how far back from the face of the bank the rock has been shattered or cracked, and sometimes where shoring is omitted large masses suddenly slide into trenches. When the banks are very treacherous it may be wise to provide close sheeting, but with trenches of moderate depth this is not generally necessary, as frequent stay-braces or skeleton sheeting will prevent the rock from sliding. The shoring of rock trenches, and especially trenches in rock overlaid with earth, is likely to be unsatisfactory and expensive because of the derangement of braces and shoring by blasting operations. It is difficult to avoid this trouble by any method of sheeting, but much can be done to lessen the danger of blowing out shoring by the use of care and judgment in the blasting.

Angle of Repose of Soils.—"The angle of repose," designated as ϕ, is the greatest angle above the horizontal plane at which the material under consideration will lie without slipping or sliding.

The angle of repose of various kinds of earth has been found experimentally, but varies greatly according to local conditions. Either increasing or decreasing the moisture in natural soils may decrease the angle of repose and increase the pressure developed. Rough average values of the angle of repose and weights of several soils are given in Table 46, taken from "A Treatise on Masonry Construction" by Baker, to which have been added the values of $\frac{1 - \sin \phi}{1 + \sin \phi}$. These values are of little practical importance but are given to show the values which are generally used in discussions of the theory of earth pressure, and to give a general idea of how they may vary. Where the earth pressure is applied to a vertical plane and the surface of the earth is horizontal, the resultant pressure is obtained by the formula

$$P = \frac{wh^2}{2} \times \frac{1 - \sin \phi}{1 + \sin \phi}$$

Where P = resultant pressure
w = weight of 1 cu. ft. of earth
h = height of bank
ϕ = angle of repose.

According to this formula the pressure developed by a soil having an angle of repose of 15° is nearly 3-1/2 times as great as the pressure developed by the same soil if its angle of repose were 45°.

TABLE 46.—ANGLE OF REPOSE AND WEIGHT OF DIFFERENT KINDS OF EARTH

Kind of earth	Angle of repose		$\frac{1 - \sin\phi}{1 + \sin\phi}$	Weight, lb. per cu. ft.
	ϕ	Slope[1]		
Alluvium...	18°	3 to 1	0.53	90
Clay, dry . ..	26°	2 to 1	0.39	110
Clay, damp. . .	45°	1 to 1	0.17	120
Clay, wet	15°	3.2 to 1	0.59	130
Gravel, coarse . .	30°	1.7 to 1	0.33	110
Gravel, graded sizes	40°	1.2 to 1	0.22	120
Loam, dry.... .	40°	1.2 to 1	0.22	80
Loam, moist. . .	45°	1 to 1	0.17	90
Loam, saturated	30°	1.7 to 1	0.33	110
Sand, dry .. .	35°	1.4 to 1	0.27	100
Sand, moist .	40°	1.2 to 1	0.22	110
Sand, saturated. .	30°	1.7 to 1	0.33	120

[1] Ratio of horizontal to vertical dimension.

Cohesion.—The methods ordinarily used for calculating earth pressures disregard the cohesion of the particles of soil. This quality varies greatly with different soils and also, in any particular soil, with its moisture content and degree of compression. Clean dry sand and gravel have little cohesion. In clay it is an important quality factor. It is this force which makes it possible to excavate a trench to a considerable depth without shoring. In clean, loose, dry sand, it is not generally possible to excavate to any material depth without causing the banks to slide or roll in, but if the sand is moist the excavation may be carried to a depth of 4 to 6 ft. without caving. Alluvium, hardpan and clay banks from 10 to 15 ft. high will often stand for several days and even in some instances for weeks without caving.

It is frequently observed that a given soil will have different cohesive qualities when under different pressures. It therefore seems logical to assume that the cohesive qualities of a soil will increase with the increase in depth of the excavation, and also to assume that the angle of repose will vary in a corresponding manner, and will increase with the depth of the trench. An increase in the water content of the soil is likely to be encountered as the excavation is carried down, however, with a corresponding decrease of the angle of repose in most cases. These assumptions should not be carried too far, as soils rarely are homogeneous and of uniform character from top to bottom of excavation, strata of different soils being frequently encountered.

Lack of Adhesion.—In considering earth pressures both the cohesive and adhesive qualities of the soil are generally included under the term cohesion, as it is very difficult to separate them. The soil, however, does not readily establish adhesive qualities as distinguished from cohesive qualities. This is well illustrated by the fact that if a trench has at some previous time been excavated parallel and relatively near to a new trench, the soil, if allowed to yield, will almost always crack on or cave to the line of the original trench, showing that practically no adhesion exists between the original virgin soil and that refilled into the old trench. This condition exists even after the trench has been backfilled and subjected to the conditions of nature for many years, and is one which must always be taken into account in planning for the bracing of a new excavation. In many cases, it is necessary to sheet and brace trenches solely because at some previous time the soil near them has been excavated and the bonds of cohesion broken, no bonds of adhesion having since been established. For these reasons, the bracing and shoring of trenches in virgin soil is very different and often much simpler than similar work in the older city streets which have been subject to frequent excavation.

Tendency of Soil Conditions to Change.—There is a tendency for the conditions affecting the need of shoring to vary from time to time. In most cases the banks will be found quite stable and apparently exercising no marked lateral pressure when first excavated, and, except in gravel, the excavation, if made quickly, may usually be carried to a considerable depth; but as the banks are allowed to stand, it will be noticed that the soil gradually, and sometimes rapidly, changes in character, expanding from release of pressure or other cause, showing cracks at the surface, raveling and flaking off in small pieces. Some of these changes may be due to drying out of the moisture in the banks, or on the other hand to an increase in moisture, in either case reducing the cohesive qualities of the soil. The increase in moisture often results from the gradual seepage of water, from water-bearing strata cut by the excavation, into the soil of the banks, tending to soften certain strata relatively dry before the excavation of the trench changed the conditions. In cities there are often leaks in water pipes and sewers, the drainage from which will work toward a nearby trench and cause a gradual saturation of the lower portions of the banks. Sudden and great changes are often caused by rains, which in a short time may saturate from top to bottom a bank which had before contained only enough moisture to assure its stability.

While the tendency toward changed conditions, due to a decrease or increase in the moisture in the soil, cannot be over-emphasized, the changes due to other causes are equally important and productive of danger to life and property. The most potent of these is the failure to sheet and brace the trench properly, thus causing voids behind the sheeting. Such voids, once formed, permit the gradual loosening of the soil, from the vibration caused by driving the sheeting and braces, the operation of the excavating machinery and the passing of cars or trains. It is often necessary to place unusual loads upon the ground close to the banks, which may cause the soil to yield if there are voids behind the sheeting. Movements of the earth due to any of these causes result in changed, and often greatly increased, pressures and loads upon the sheeting, and may also result in changing the point of application of the resultant earth pressure upon it.

CALCULATION OF EARTH PRESSURES

Rankine's Formula.—Methods of calculating the pressure exerted by the earth against vertical and inclined planes have been evolved by Coulomb, Rankine and several later investigators. Most of these methods are based upon the fundamental assumptions that pressure is exerted laterally by a wedge-shaped prism of earth, *ABC*, Fig. 102, which is just on the point of sliding along a plane of rupture, *BC*, and exerts its greatest pressure at the toe. Fig. 102 illustrates a trench with the surface of the ground horizontal on one side and at an angle θ with the horizontal plane on the other. The symbols used in the figure and in the formulas, are as follows:

w = weight of unit volume of earth, assumed to be 100 lb. per cubic foot.
P = resultant pressure of the mass of earth, prevented from sliding by sheeting.
H = horizontal component of P.
ϕ = the angle of repose *DBE* of a particular soil.
θ = angle, *DAF*, of surface of surcharge, with the horizontal plane.
h = depth at any point below surface.
p = intensity of horizontal pressure, in pounds per square foot, at any depth, h, below the surface.

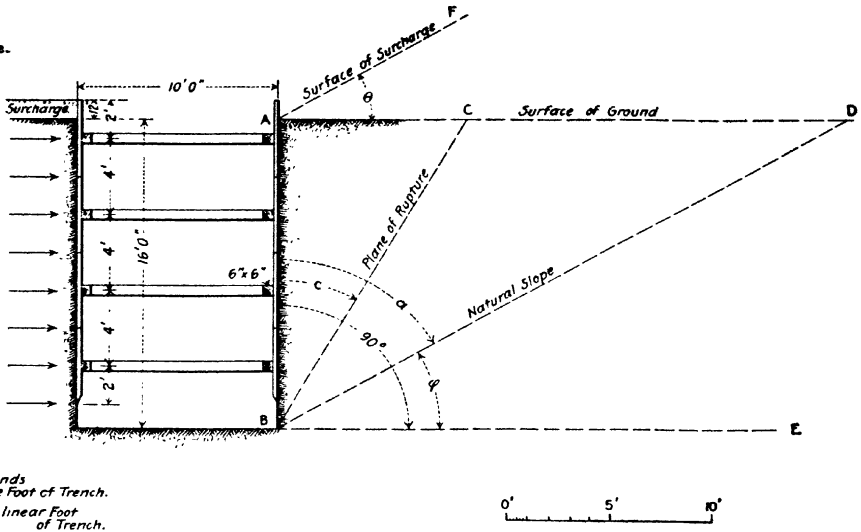
This theory disregards cohesion, which is generally an active force of varying amount in all soils.

Rankine's formula, modified for special problems, is convenient for calculating earth pressures and is typical of the others. This formula is

$$P = \frac{wh^2}{2} \cos \theta \times \frac{\cos \theta - \sqrt{\cos^2 \theta - \cos^2 \phi}}{\cos \theta + \sqrt{\cos^2 \theta - \cos^2 \phi}}$$

In evolving this formula it is assumed that the plane against which

	Earth Pressure. — After Meem.	Water Pressure. —	Earth Pressure. — After Rankine
Intensity *	925	0	0
Total ☐	3238	500	266
Intensity	694	250	133
Total	2310	1500	800
Intensity	461	500	267
Total	1384	2500	1334
Intensity	231	750	400
Total	462	3500	1866
Intensity	0	1000	533



* *Intensity of Pressure in Pounds per square Foot of Trench.*

☐ *Total Pressure in Pounds per linear Foot of Trench.*

FIG. 102.—Earth pressures in trench by different assumptions.

In this table the figures of total pressures in pounds per linear foot of trench refer to the section between the preceding and following points of application at which the intensities are given, and these amounts are the total pressures per linear foot transmitted to the ranger by the sheeting for that section. Only the left-hand portion of the diagram is referred to in Mr. Meem's notes on page 277.

the lateral pressure is exerted, or the sheeting, is vertical and that the resultant earth pressure, P, is parallel to the surface of the ground.

Ordinarily in cases where the earth is sloped away and up from the vertical plane it may be assumed that the angle θ between the surface of the ground and the horizontal plane is equal to the angle of repose ϕ, in which case the formula becomes,

$$P = \frac{wh^2}{2} \cdot \cos \phi$$

If there is no surcharge and the surface is horizontal θ will equal zero, and the formula becomes,

$$P = H = \frac{wh^2}{2} \times \frac{1 - \sin \phi}{1 + \sin \phi}$$

In all cases if it is assumed that the direction of the resultant pressure P is parallel to the surface of the ground

$$H = P \cos \theta$$

If the angle of repose is reduced to zero, as in the case of a liquid, the formula becomes,

$$P = H = \frac{wh^2}{2}$$

In all cases P varies as the square of the height of the bank, as in the case of a liquid, and it has therefore been assumed by most engineers that the resultant earth pressure, P, is applied to the sheeting at a point one-third the height from the bottom. The intensity of pressure at any point may be found by the formula,

$$p = \frac{2P}{h}$$

It is generally assumed in calculations of this kind that the angle of repose is 30°. The formula then becomes,

$$P = H = \frac{wh^2}{6}$$

and

$$p = \frac{wh}{3}$$

These last formulas are simple and for practical purposes are all that need be used to obtain a general idea of the forces which sheeting and bracing are likely to have to withstand.

If an additional load is placed upon the banks, other than that due to earth cast out of the trench which, if sloped back at an angle equal to the angle of repose, or say 30°, can be cared for by the formula, the weight of such additional load should be calculated and reduced to an equivalent depth of superimposed earth, thus correspondingly increasing *H*, in which case the surface should be assumed to be horizontal. In estimating the loads likely to come upon the shoring, due consideration

TABLE 47.—INTENSITY OF HORIZONTAL PRESSURE AND TOTAL HORIZONTAL PRESSURE OF EARTH AT VARIOUS DEPTHS

($W = 100$ pounds per cubic foot; $\phi = 30°$. *H* and *P* are per foot of trench)

	Horizontal surface		Surcharges $\theta = 30°$		
Depth h ft	$p = \frac{1}{3}wh$ pounds	$H = P = \frac{1}{6}wh^2$ pounds	h ft	$p \cos\theta = \frac{3}{4}wh$ pounds	$H = P\cos\theta = \frac{3}{8}wh^2$ pounds
1	33	17	1	75	38
2	67	67	2	150	150
3	100	150	3	225	338
4	133	267	4	300	600
5	167	417	5	375	938
6	200	600	6	450	1,350
7	233	817	7	525	1,838
8	267	1,067	8	600	2,400
9	300	1,350	9	675	3,038
10	333	1,667	10	750	3,750
11	367	2,017	11	825	4,538
12	400	2,400	12	900	5,400
13	433	2,817	13	975	6,338
14	467	3,267	14	1,050	7,350
15	500	3,750	15	1,125	8,438
16	533	4,267	16	1,200	9,600
17	567	4,817	17	1,275	10,838
18	600	5,400	18	1,350	12,150
19	633	6,017	19	1,425	13,538
20	667	6,667	20	1,500	15,000
21	700	7,350	21	1,575	16,538
22	733	8,067	22	1,650	18,150
23	767	8,817	23	1,725	19,838
24	800	9,600	24	1,800	21,600
25	833	10,417	25	1,875	23,438
26	867	11,267	26	1,950	25,350
27	900	12,150	27	2,025	27,338
28	933	13,067	28	2,100	29,400
29	967	14,017	29	2,175	31,538
30	1,000	15,000	30	2,250	33,750

should be given to vibration, such as that caused by passing trains or other vehicles, the operation of excavating machinery and the driving of piles. The effect of jar cannot be calculated, and the allowance made for it must be a matter of judgment.

Table 47 gives the intensity of the horizontal pressure in pounds per square foot and the total horizontal pressure in pounds per linear foot of trench at various depths, calculated by the foregoing formulas, assuming the angle of repose to be 30 deg. in all cases and the surface of the earth horizontal, and also rising at an angle of 30 deg.

A typical trench 16 ft. in depth, shored with a single set of sheeting, is illustrated in Fig. 102. The sheeting is shown driven to a depth of only 15 ft., or to a point 1 ft. above the bottom of the trench. As more or less load is usually placed upon the banks, it has been assumed in the following calculations that the sheeting must also support a surcharge equivalent to an additional depth of 1 ft. of trench. This figure and the calculations are given simply to illustrate the methods and not as suggestive of actual loads likely to be placed upon the shoring.

To simplify the calculations it has been assumed that the typical trench is sheeted with poling boards 4 ft. in length, and that each brace must carry the load supported by the set of poling boards against which it is placed. If the trench were sheeted with the ordinary vertical sheeting the pressure would be somewhat differently distributed, because the sheeting would act like a continuous beam.

The results of these calculations by the Rankine formula are given in Col. 4, Fig. 102. It will be seen that the intensity of pressure varies with the depth of trench, as does also the total pressure, the maximum load being upon the bottom brace.

Hydrostatic Pressure Sometimes Exerted on Sheeting.—Occasionally conditions are such that water will accumulate in the soil back of the sheeting, so that the pressure exerted may approximate that which would be due to an equal depth of water. This is probably the most severe condition encountered in the sheeting of trenches, except under extraordinary circumstances and unless it can be conceived that a bank of sand might thus be converted into a fluid or quicksand, having a weight greater than that of a corresponding volume of water.

Such a theory must be based upon the assumption that the particles in the mass of earth, held in position by the sheeting, are devoid of cohesion and free to move as are the particles of a fluid, and that the pressure from the overlying particles may be transmitted vertically to particles below, and laterally through them to the sheeting, in other words, that the earth, if permitted, will flow like a fluid. If this theory were correct in all respects it would follow that the pressure of the soil in the banks would be exerted on the soil in the bottom of the trench, causing it to flow up or rise within the sheeting with a pressure equal to that exerted on the sheeting at the bottom of the bank. Experience indicates that this condition rarely, if ever, exists, although it is not uncommon to encounter expansion in soils and water-bearing strata of fine sand which will flow through cracks in the sheeting and which will at times boil up within the trench. Such flowing sand, however, usually reaches a state of equilibrium after it has flowed into the trench to a depth of a few feet above its original bottom. This would seem to indicate that even under these conditions the material is not free to act like a fluid, else the trench would become filled with the quicksand. It seems probable that only a limited quantity of the sand near the trench is converted to a fluid condition and that after this has flowed into the trench and created a greater pressure within than formerly existed, there is an insufficient quantity of fluid sand to continue filling the trench and conditions for a time become similar to those previously existing, when the banks of the trench follow the laws of earth rather than of fluids. If, however, there is an ample supply of water the sheeting may be subject to pressures closely approaching those due to a similar depth of water.

For the purpose of comparing the hydrostatic pressure with that which may be developed by the soil, in accordance with Rankine's theory, the hydrostatic pressures have been calculated for the typical trench, Fig. 102. These pressures are probably very rarely, if ever, encountered in practice unless it be in connection with subaqueous work, but they may be helpful as indicating the extreme limit of pressure which may be encountered.

It has been assumed in making these calculations that the height of the fluid exerting pressure on sheeting was the same as the height of the banks of the trench and the pressures have been determined as follows:

h = the height of fluid, Fig. 102.

w = weight of water, 62.5 lb. per cubic foot.

$P = \frac{wh^2}{2}$ = total pressure on sheeting for a trench 1 ft. in length.

$p = wh$ = intensity of pressure at any point.

Under hydrostatic conditions the resultant pressure would, of course, be at a point one-third of the distance from the bottom to the top of the trench.

It will be seen by comparing Cols. 3 and 4, Fig. 102, that the Rankine formula gives pressures which are approximately half as great as the hydrostatic pressures, assuming an angle of repose of 30 deg., the weight of earth to be 100 lb. per cubic foot and the surface of the ground to be horizontal.

Meem's Theory of Earth Pressures.—In a valuable article upon "The Bracing of Trenches and Tunnels, with Practical Formulas for Earth Pressures," Transactions American Society of Civil Engineers, vol. lx,

p. 1, J. C. Meem presented a theory of the action of the banks of a trench by which the resultant pressure acts at a point two-thirds the distance from the bottom to the top instead of one-third, as proposed by Rankine, Coulomb and others. While this theory may be supported by many conditions which have been encountered in work of this kind, experience leads us to say a word of caution, because there have been so many cases in which the pressures have increased greatly with apparent lowering of the point of application of the resultant pressure as the trench stood open. Referring to Fig. 102 and changing the symbols from those used by the author to those used herein, Mr. Meem may be quoted as follows:

> "In all his experience, the writer has used the diagram (Fig. 102) for calculations of earth pressure, whether applied to retaining walls or to sheeting and bracing.
>
> "If AB be the line of the sheeting, and DB the natural slope of the earth, ϕ being the angle of repose, then the mass of earth causing pressure against the line AB is contained within the triangle, DAB.
>
> "The weight of the earth in this triangle rests on DB, and its thrust is transmitted to AB, not through the toe of each layer at the foot of its slope line, but by the arching effect of this earth between the lines, AB and DB.
>
> "For purposes of calculation, it is probably not far from correct to assume that a line, CB, bisecting this angle, ABD, measures with AB an area equivalent to the weight transmitted as thrust against this line, AB. Also, it is true that the center of pressure against AB is where a perpendicular from the center of gravity of the triangle, ACB, meets this line.
>
> "The writer is fully aware that in making this assumption he is going contrary to the general theory, which assumes that earth pressure acts along the line of rupture and parallel with that line, and is therefore greatest at the toe, but he wishes to state that this theory is not borne out in actual practice, and *that all closely sheeted well-braced trenches invariably show a heavier pressure at the top than at the bottom.*"

Mr. Meem stated that if particles of soil were absolutely without friction and if their weight were transmitted cumulatively entirely and directly to the bottom, then the older theory, that the resultant pressure acts at one-third of the distance from bottom to top of the bank, would be true. He does not believe this condition to exist in nature, however, and points out that a bank seldom exerts much lateral pressure at the bottom and that it may usually be undercut near the bottom by the use of poling boards and very light bracing, and that if the bracing above has been poorly done, so that the stability of the mass has been disturbed, the pressure of the soil will manifest itself "by the continual dropping of masses of material from above, rather than as a constant pressure, as would have been the case had the material been full of water or absolutely frictionless. . . . It may be, and the writer has frequently observed also, that the lower part of a trench may be left unsheeted . . . . and for a considerable distance longitudinally in clays and moist sands, without disturbing the stability of the face, and yet more or less heavy pressure may be observed in the bracing above." He stated that this can only be explained on the theory of the arching effect of the material above, one buttress of the arch being the sheeting and the other the plane of repose. He pointed out further that heavy pressures are frequently developed in the top braces and rangers while excavation is being safely done beyond the limits of the sheeting at the bottom and "that it would be suicidal to remove any one of the braces near the top of the excavation, particularly after the ground had stood for any considerable time."

Changing the symbols and referring to Fig. 102, Mr. Meem's formula is as follows:

If ϕ = the angle of repose,
$a = 90° - \phi$,
$c = \frac{a}{2}$ the angle between the line of rupture and the sheeting,
h = height,
w = weight of 1 cu. ft. of earth.

Then the area $ABC = \frac{h^2 \tan c}{2}$, and the weight of the mass of earth causing pressure on $AB = \frac{wh^2 \tan c}{2}$.

"The resultant pressure of this mass would occur at two-thirds of the height.

"In the case of a well-sheeted and braced bank, there would be no overturning moment, but there would be a thrust, represented by the general tendency of the triangle ABC, to slide along the line BC, and therefore move out and exert pressure in a horizontal direction."

In summing up his opinion, Mr. Meem states that he believes that the action of the earth pressure in properly braced trenches is more closely allied to that of a coherent solid than to that of an aqueous or frictionless mass.

If Mr. Meem's theory of the action of the earth in causing pressure upon sheeting is correct, the pressure at or near the bottom of the trench would be much lighter than that near the top and it would, therefore, be logical to use lighter timbering at the bottom as has been done by Mr. Meem with apparent success. The conditions which he points out as proving that the pressure at the bottom of a trench is lighter than at the top are certainly worthy of consideration because they are commonly observed. It is not improbable, however, that they are due to the fact that the bonds of cohesion in the bottom layers of the soil have not been broken to the extent that they have been severed near the top, except where the excavation is in wet material. The angle of repose of the soil naturally becomes greater the deeper the excavation is made, and the cohesive forces are undoubtedly greater because of the greater compression upon the soil. These assumptions, if well founded, are sufficient reason for the lack of pressure so often noted at the bottom of trenches, but it is a serious question if these assumptions or the conditions actually observed in practice warrant the adoption of Mr. Meem's theory. As has been herein pointed out several times, the conditions do change from day to day as a trench remains open, and there have been many instances where a bank has apparently exerted little or no pressure at the bottom, when first exposed, but where conditions have so changed that very great pressure has been exerted upon the bottom timbering before the excavation was refilled. It is this change in conditions which leads most practical sewer builders to adopt at least as heavy timber for the bottom as the top of their trenches, and most engineers to the adoption of the Rankine theory of earth pressures. In a word, it may be said that Mr. Meem's theory is well supported by conditions observed when trenches are first excavated, or so thoroughly well-braced that the bonds of cohesion are not severed to any material extent, but that conditions approach the theory of a frictionless mass, after Rankine, as these bonds of cohesion are severed and the banks change their physical condition and position.

Unfortunately, relatively little timbering is so well done that no movements or changes of this kind take place and trenches must continue to be so braced as to be safe under the changed conditions. In this connection it may be of interest to cite observations made during the construction of a large well described in an article by Leonard Metcalf entitled "Difficulties Encountered in Building the Storage Well for the Sewerage System of Concord, Mass.," *Jour. Assoc. Eng. Socs.*, vol. xxiv, page 277. The material at the site of this well was very fine sand with sufficient water to make it flow. The bracing was of the cellular, fan-shaped type. When the sheeting began to fail because of the movement of the material and the changed condition of it, the bottom line of 10 × 10-in. yellow-pine timbers was reduced to 6 in. across the grain by the pressure on the braces, although the top set showed no such fatigue or crushing. The timber structure had stood for months before the heavy pressures developed.

In the discussion following the presentation of Mr. Meem's paper, many points were brought out, some of which may be briefly quoted with interest to the reader:

"Quick operation spares many a patient, and the thought persistently comes, with respect to attempts at formulating probabilities, that what might be accurate, allowable, and advisable for an energetic construction gang with a clear field and all obstacles, legal and official, removed, might be questionable when the above agencies have full play for a considerable time in a busy street" (Horace J. Howe, p. 24).

"The properties of earth with respect to adhesion and friction are so variable that the engineer should never trust to tables or to information *obtained from books to guide him in designing earthworks, when he has it in his power to obtain the necessary data either by observation of existing* earthworks in the same stratum, or by experiments" (Rankine, quoted by Howe, p. 25).

"*The experienced man will probably prefer to rely on his own judgment, as every case has to be studied by itself, and the more one has to do with earth or water pressures the more respect he has for their power and the less liberty he takes with them.* There is probably not an experienced foundation man in the country who has not seen cofferdam bracing collapse, sometimes at the bottom, sometimes half way up, and elsewhere.

"In discussing fluid pressure, the author doubts if the full hydrostatic pressure would be found at the bottom . . . . the conclusion is that in some cases the full pressure does not occur, in many it does, while in others the pressure is much greater than the hydrostatic head would call for.

"In pneumatic caissons in quicksand in New York City, where the caissons are sunk with as little disturbance of the ground as possible, it is found necessary to keep the air pressure almost exactly at the theoretical water pressure. Many want to calculate the pressure at from 90 to 100 lb. per cu. ft., including the weight of water and sand" (T. Kennard Thomson, p. 46).

"Do not take chances, but be safe You must not put in a 6 × 6-in. stick because 'theory' says it will hold, but double the size, and perhaps double it again, unless you are dead sure of every condition surrounding the work.

"The importance of driving the braces tight in an excavated trench, to prevent as far as possible the movement of earth or sand back of the sheathing, has already been brought out. In the speaker's opinion, this is a matter that deserves the closest attention, for, from the moment the movement of the material commences, the trouble begins" (R. A. Shailer, p. 49).

"In the construction of the Brooklyn Subway, with which the writer is connected, it was necessary to excavate a trench averaging 30 ft. deep and 5000 ft. long. The bank was composed of sand and gravel with some few boulders. The bracing, designed by Mr. Meem, had the larger braces at the top and smaller braces when approaching the bottom. In no single instance has any failure of the lower and lighter braces been observed. Many instances of bending of the upper rangers, however, have been noticed" (H. P. Moran, p. 49).

"The error most commonly made in applying theory to practice is the assumption that the angle of repose remains constant, no matter what the depth; this, of course, is not tenable. There is no reason why it should be constant, and every reason why it should not be.

"In soil that has stood for ages in its original condition, the lower layers will be very much more compacted than the upper ones, by reason of the pressure of the earth above. If excavation is carried deep enough, it is found that the earth is almost in the condition of rock, it is so compactly consolidated. By applying sufficient pressure to a sample of earth, say in a hydrostatic press, it would be possible to make it almost as firm as soft rock.

"The angle of repose, therefore, would increase with the depth below the surface in some proportion as the compactness of the soil increased. This condition would apply, not only to clay and loam, but also to sand when not under the water line" (Eugene W. Stern, p. 54).

Mr. Stern, by the use of Coulomb's formula and by increasing the angle of repose as the trench became deeper, reached practically the results reached by Mr. Meem by the use of his theory. Mr. Stern closed his discussion with the statement that the principles enunciated by Mr. Meem are "radically wrong."

CALCULATION OF SIZES OF RANGERS AND BRACES

The load on the rangers may be calculated with the aid of Rankine's formula. The results of such a calculation, assuming the surface of the ground to be horizontal, the angle of repose to be 30 deg. and the weight of the soil to be 100 lb. per cubic foot, are given in Table 49, Col. 2. These calculations are based upon the typical trench illustrated by Fig. 102, assuming that it is 10 ft. wide to the outside of the sheeting. In practice, where the trench is in cohesive material and is not likely to stand open a long time, it will be safe to assume one-third to one-fourth of the earth pressures given, and in cases where the *material has little cohesion* and there is no danger of hydrostatic pressure, it will be safe to assume one-half the values given.

The maximum bending moments on the rangers, spaced as indicated in Fig. 102, are given in Col. 3.

In calculating the sizes of timbers to be used, the allowable stresses have been based upon the values given for spruce in Table 48, taken from the Manual of the American Railway Engineering Association, 1911. The working unit stresses given in this table are intended for railroad bridges and trestles having to sustain moving loads causing heavy impact, and in calculating the sizes of rangers the extreme fiber stress allowable in bending has been increased 50 per cent., or to 1500 lb. per square inch, as the load upon these in trench work more closely follows the static type and as the structure is shorter lived and a lower factor of safety is permissible.

In Col. 5, Table 49, are given the sizes of rangers required to withstand the pressure developed by the earth, as given in Col. 2. These sizes are based upon the common practice of using rangers with their wider sides against the sheeting. The sizes vary from 6 × 6 in. near the top to 8 × 12 in. near the bottom and much exceed the sizes used under ordinary conditions.

The rangers are assumed to be 16 ft. long and the braces spaced 8 ft. center to center horizontally, thereby making the rangers continuous over one support. This does not make the ranger any stronger under a uniformly distributed load, but does make it stiffer and changes the reactions and shear. The reaction on the end brace is that due to one ranger only. For braces where a butt joint in the ranger occurs, this amount should be doubled. If the rangers are only 8 ft. long, the reaction on the end support and the maximum shear will be $wl/2$ in each case.

The reaction on the end and center braces is given in Cols. 6 and 7. The length of the braces varies from 100 to 104 in., in accordance with the size of the rangers.

The size of the braces has been figured by the following formula:

Working stress per square inch $= 1100\ (1 - \frac{l}{60d})$, the formula for columns having a length in excess of 15 diameters.

d = least width of brace in inches

l = unsupported length of brace in inches.

For short columns the working stress given in Col. 12 of Table 48 may be used directly.

The sizes of the end and center braces calculated in this manner are given in Cols. 9 and 10, Table 49, and are found to be smaller than those ordinarily used.

The maximum shear on the rangers, given in Cols. 11 and 12, is found in all cases to be less than the average ultimate shear given in Col. 7, Table 48, but greater than the working shear given in Col. 8, Table 48. It is probable, however, that even under conditions which might make it possible for the earth to exert the pressures indicated in Col. 2, Table 49, rangers of the sizes indicated in Col. 5 will be sufficiently strong to withstand the shearing stress upon work of such temporary nature.

The maximum compressive stresses of the center braces upon the rangers are given in Col. 13 and from them have been calculated, Col. 14, the sizes of braces which are large enough to reduce the compressive stress upon the rangers to 300 lb. or less per square inch. By comparing Cols. 10 and 14, it appears that the required size of a brace is limited by the compressive stress exerted upon the ranger, rather than by the compressive stresses in the braces themselves. This fact is emphasized by numerous instances in the experience of practical sewer builders, where the earth pressures have been sufficiently heavy to cause the braces to cut into the rangers to an appreciable extent, but have not been sufficient to cause distress in the braces themselves.

As has already been pointed out, the cohesive qualities of soil in most cases prevent the immediate development of pressures even approaching those indicated by the use of the Rankine formula. Sewers are usually constructed with sufficient rapidity so that the trenches are not allowed to stand open for long periods of time during which the cohesive qualities of the soil are subject to radical change. For these reasons, it is probable

TABLE 48.—WORKING UNIT-STRESSES FOR STRUCTURAL TIMBER
(Pounds per Square Inch)

Kind of timber	Bending			Shearing				Compression						Ratio of length of stringer to depth
	Extreme fiber stress		Modulus of elasticity	Parallel to the grain		Longitudinal shear in beams		Perpendicular to the grain		Parallel to the grain		For columns with $l/d = < 15$, working stress	Formulas for working stress in long columns over 15 diameters	
	Average ultimate	Working stress	Average	Average ultimate	Working stress	Average ultimate	Working stress	Elastic limit	Working stress	Average ultimate	Working stress			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Douglas fir	6,100	1,200	1,510,000	690	170	270	110	630	310	3,600	1,200	900	1,200(1–l/60d)	10
Longleaf pine	6,500	1,300	1,610,000	720	180	300	120	520	260	3,800	1,300	980	1,300(1–l/60d)	10
Shortleaf pine	5,600	1,100	1,480,000	710	170	330	130	340	170	3,400	1,100	830	1,100(1–l/60d)	10
White pine	4,400	900	1,130,000	400	100	180	70	290	150	3,000	1,000	750	1,000(1–l/60d)	10
Spruce	4,800	1,000	1,310,000	600	150	170	70	370	180	3,200	1,100	830	1,100(1–l/60d)	....
Norway pine	4,200	800	1,190,000	590[1]	130	250	100		150	2,600[1]	800	600	800(1–l/60d)	....
Tamarack	4,600	900	1,220,000	670	170	260	100		220	3,200[1]	1,000	750	1,000(1–l/60d)	....
Western hemlock	5,800	1,100	1,480,000	630	160	270[1]	100	440	220	3,500	1,200	900	1,200(1–l/60d)	....
Redwood	5,000	900	800,000	300	80			400	150	3,300	900	680	900(1–l/60d)	....
Bald cypress	4,800	900	1,150,000	500	120			340	170	3,900	1,100	830	1,100(1–l/60d)	....
Red cedar	4,200	800	800,000					470	230	2,800	900	680	900(1–l/60d)	....
White oak	5,700	1,100	1,150,000	840	210	270	110	920	450	3,500	1,300	980	1,300(1–l/60d)	12

These unit-stresses are for green timber and are to be used without increasing the live load stresses for impact

[1] Partially air dried.

l = length in inches.

d = least side in inches.

Note.—The working unit-stresses given in this table are intended for railroad bridges and trestles. For highway bridges and trestles the unit-stresses may be increased 25 per cent. For buildings and similar structures in which the timber is protected from the weather and practically free from impact, the unit-stresses may be increased 50 per cent. To compute the deflection of a beam under long-continued loading instead of that when the load is first applied, only 50 per cent. of the corresponding modulus of elasticity given in the table is to be employed.

(Reference) Manual of the American Railway Engineering Association. Edition of 1911, page 153.

TABLE 49.—SIZES OF RANGERS AND BRACES FOR TYPICAL TRENCHES

	Ranger; assume clear span l = 8 ft	Uniform load on ranger per foot, w [1]pounds per ft	Maximum bending moment, $\frac{1}{8}wl^2 \times 12$ M inch-pounds	Values of $bd^2 = \frac{6M}{1500}$ where b is the breadth and d the depth	Size of spruce ranger, inches	Reaction on end support, $\frac{3}{8}wl$ pounds	Reaction on center support, $\frac{10}{8}wl$ pounds	Length of brace unsupported, inches	End brace size, inches	Center brace size, inches	Maximum shear on ranger $\frac{5}{8}wl$ pounds	Maximum shearing stress on ranger, pounds per square inch	Maximum compressive stress on ranger opposite center brace perpendicular to grain, lb per sq in	Size of center brace to make compressive stress = <300 lb per square inch
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rankine earth	1	266	25,540	102	6 × 6	798	2,660	104	2 × 4	4 × 4	1,330	37	166	4 × 4
	2	800	76,800	307	6 × 10	2,400	8,000	104	4 × 4	4 × 4	4,000	67	500	6 × 6
	3	1,334	128,100	511	8 × 8	4,002	13,340	100	4 × 4	4 × 6	6,670	104	556	6 × 8
	4	1,866	179,230	717	8 × 12	5,598	18,660	100	4 × 4	6 × 6	9,330	97	518	8 × 8
	Average	. . . . . .	. .	. .				102						
Water pressure	1	500	48,000	192	6 × 6	1,500	5,000	104	4 × 4	4 × 4	2,500	70	312	4 × 6
	2	1,500	144,000	576	8 × 10	4,500	15,000	100	4 × 4	4 × 6	7,500	94	625	8 × 8
	3	2,500	240,000	960	10 × 10	7,500	25,000	96	4 × 4	6 × 6	12,500	125	695	10 × 10
	4	3,500	336,000	1,345	10 × 14	10,500	35,000	96	4 × 6	6 × 8	17,500	125	730	10 × 12
	Average							99						
Meem earth	1	3,233	310,500	1,242	10 × 14	9,699	32,330	96	4 × 4	6 × 8	16,165	115	674	8 × 14
	2	2,310	221,800	887	10 × 10	6,930	23,100	96	4 × 4	6 × 6	11,550	116	642	8 × 10
	3	1,384	132,800	532	8 × 10	4,152	13,840	100	4 × 4	4 × 6	6,920	87	576	6 × 8
	4	462	44,350	178	6 × 6	1,386	4,620	104	2 × 4	4 × 4	2,310	64	289	4 × 4
	Average							99						

[1] See Fig 102.

Notes—Assumed depth of trench = 16 ft. Trench 10 ft wide from outside to outside of sheeting. Sheeting 2 in. thick. Rangers are 16 ft. long and placed with longer side vertical, *i e*, parallel to neutral axis Spacing of rangers vertically = 4 ft center to center Center of first ranger 2 ft. below surface. Bottom of trench 2 ft. below center of fourth ranger. Braces spaced 8 ft. center to center horizontally.

that the pressures indicated in Col. 2, Table 48, are much in excess of those which will be encountered in ordinary sewer construction and it is probable that the unit working stresses already suggested may be

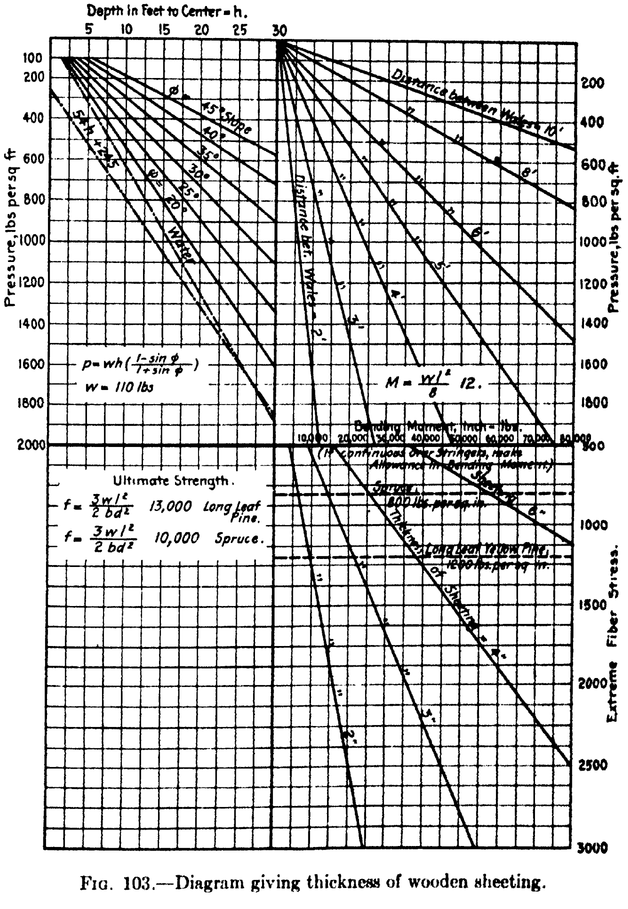


Fig. 103.—Diagram giving thickness of wooden sheeting.

safely substituted for these loads, thus reducing the sizes of rangers required.

It is customary in ordinary sewer construction to use a uniform size of rangers from the top to the bottom of the trench and also to use braces having the same depth as the rangers for convenience and interchangeability. Center braces are generally of the same size as the rangers, but the end braces are frequently made smaller as they have to

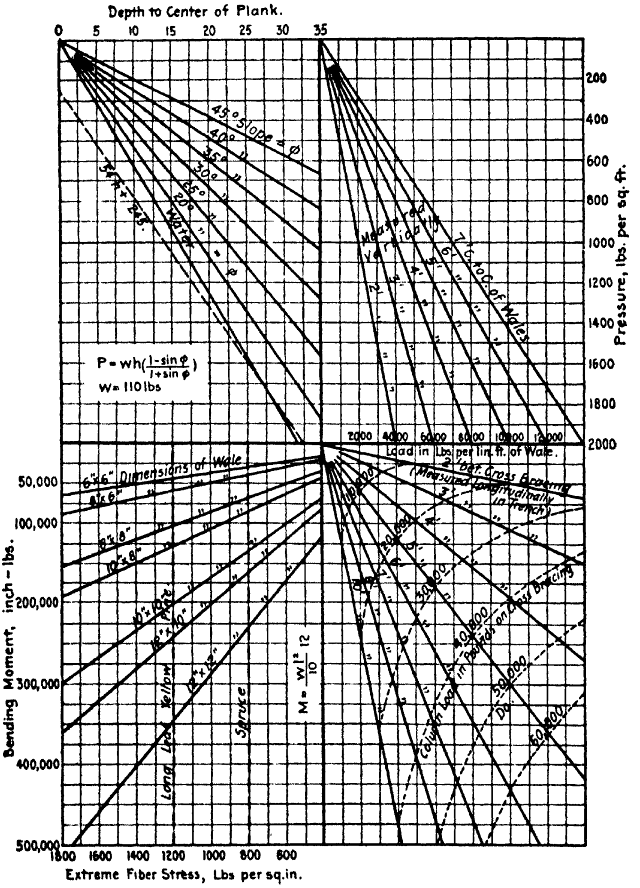


Fig. 104.—Diagram giving sizes of wales and cross-braces.

support only about half as long a panel of sheeting as the center braces. From Cols. 6 and 7, Table 49, it will be seen that the reaction on the center braces in the typical trench, Fig. 102, is 3-1/3 times as great as that upon one of the end braces. For example, where rangers are 6 × 6-in. spruce timbers, the center braces are usually 6 × 6 in. in size and the end braces are often reduced to 4 × 6 in. in size, and placed with the long side vertical.

For the purpose of making a comparison of the sizes of timbers required for shoring a trench, the results of similar calculations for water pressure and for earth pressure in accordance with Meem's theory are given in Table 49. The differences between the results obtained by the use of the theories of Rankine and Meem are very striking.

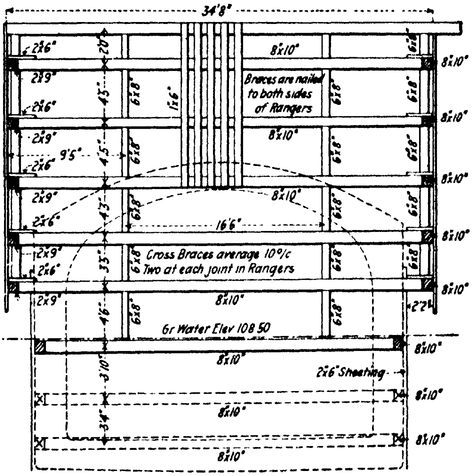


FIG. 105.—Timbering used on the Cambridge subway.

Diagrams for Calculating Thickness of Sheeting and Sizes of Rangers and Braces.—In an article published in *Engineering-Contracting*, vol. xxxiv, page 76, Frank H. Carter presents two diagrams based upon Rankine's formula by means of which the thickness of sheeting and the sizes of rangers and braces can be readily determined. In preparing these diagrams, Fig. 103 and Fig. 104, Mr. Carter has assumed the weight of earth to be 110 lb. per cubic foot, and that the angle of inclination of surcharge is equal to zero or that the surface of the surcharge is level. He suggests, however, that the earth pressures found by the diagrams be divided by 2, 3, or 4, as experience and judgment may dictate, before applying them to the other parts of the diagram.

The author may be quoted as follows:

"In closing the writer offers the following example (shown in Fig. 105) of recent trench excavation in dry sand and clay, designed and built by the Hugh Nawn Contracting Co. for the Cambridge Main Street Subway, the timbers of which had been holding up so well that the trench foreman decided to economize in the use of lumber, notwithstanding the approach of the trench to a four-story brick building within 10 ft. of the side of the trench. Stringers 10 × 8 in. and cross braces 10 ft. on center longitudinally of the trench and 4 ft. on center vertically had been used. The saving was made by increasing the vertical spacing of the stringers so that at a depth of 21 ft. they were 5 ft. 10 in., center to center. This would have stressed the 2-in. plank sheeting up to 2500 to 3000 lb. per square inch, and the wales to about the same figure, by the usual theories, but from the appearance of the timber itself there is scarcely evidence of any pressure whatever.

TABLE 50.—WOODEN BEAMS. BENDING MOMENTS IN THOUSAND INCH-POUNDS FOR A FIBER STRESS OF 1200 POUNDS PER SQUARE INCH

Width in inches	Depth in inches = d										
	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0	14.0	16.0
	$d^2 = 1$	4.0	9.0	16.0	25.0	36.0	64.0	100.0	144.0	196.0	256.0
1	0.2	0.8	1.8	3.2	5.0	7.2	12.8	20.0	28.8	39.2	51.2
2	0.4	1.6	3.6	6.4	10.0	14.4	25.6	40.0	57.6	78.4	102.4
3	0.6	2.4	5.4	9.6	15.0	21.6	38.4	60.0	86.4	117.6	153.6
4	0.8	3.2	7.2	12.8	20.0	28.0	51.2	80.0	115.2	156.8	204.8
5	1.0	4.0	9.0	16.0	25.0	36.0	64.0	100.0	144.0	196.0	256.0
6	1.2	4.8	10.8	19.2	30.0	43.2	76.8	120.0	173.0	235.0	307.0
8	1.6	6.4	14.4	25.6	40.0	57.5	102.5	160.0	231.0	313.0	410.0
10	2.0	8.0	18.0	32.0	50.0	72.0	128.0	200.0	288.0	392.0	512.0
12	2.4	9.6	21.6	38.4	60.0	86.3	153.5	240.0	347.0	470.0	615.0
14	2.8	11.2	25.2	44.8	70.0	101.0	179.0	280.0	405.0	548.0	715.0
16	3.2	12.8	28.8	51.2	80.0	115.0	205.0	320.0	462.0	626.0	820.0

M = bending moment
b = horizontal width of ranger
d = vertical depth of ranger

$$M = bd^2 \frac{1200}{6}$$

(Reference, *Engineering and Contracting*, July 27, 1910, p. 76.)

"To use Fig. 103 on the example given, enter the upper left-hand corner of the diagram with a depth of 21 ft. and a slope of $\phi = 40°$, reading 500 lb. pressure per square foot, thence running along the horizontal line to the inclined line in the upper right-hand part of the diagram reading 'Distance between wales = 5 ft.' read 19,000 in.-lb. bending moment, thence following down the 19,000 line to the inclined line in the lower right-hand part of the diagram read 2400 lb. per square inch stress on 2-in. sheeting, allowing $M = (wl^2/8)12$, (an assumption excessively on the side of safety except for the last span in a series of continuous spans). In the process of concreting the side walls, the rangers are removed, causing the 2-in. plank to span 8 ft. for a short time, instead of 4 ft. as computed. The trench was dug in material which would probably assume a slope of 40° when exposed to the weather, but the work was done quickly and thoroughly and well underdrained, hence we may assume that the earth pressures are but one-fourth of those theoretically developed. Dividing 500 by 4 we have 125 lb. per square foot pressure. Entering the upper left-hand part of the diagram with a pressure of 125 lb. per square foot and running along the horizontal line 125 lb. to the inclined line 5 ft. (distance between wales) we find a bending moment of 5000 in.-lb., thence running down the vertical line representing 5000 in.-lb. to the inclined line in the

TABLE 51.—SAFE LOADS FOR LONG-LEAF GEORGIA YELLOW-PINE COLUMNS OR BRACES. (POUNDS)

Length, ft	4 × 4 in	6 × 6 in	8 × 8 in	10 × 10 in.	12 × 12 in.
6	12,000	33,000	58,200	94,000	138,000
8	10,400	28,000	55,000	89,000	134,000
10	8,950	25,800	51,200	86,000	128,000
12	7,800	23,400	48,000	82,000	124,000
14	6,900	21,300	44,500	77,000	118,000
16	6,100	19,300	41,600	73,000	112,000
18	. .	17,600	38,800	68,000	108,000
20	. .	16,200	35,800	65,000	103,000
22	. .	15,000	33,600	61,500	98,000
24	. .	13,700	31,300	57,500	93,500
26	. .	. .	29,400	55,000	88,500
28	. .	. .	27,500	51,500	85,000
30	. .	. .	25,900	49,000	80,500
32	. .	. .	24,300	47,000	77,000
34	. .	. .	. .	44,000	74,500
36	. .	. .	. .	42,000	70,500

Based on formula of U. S. Department of Agriculture, Div. of Forestry.

$$P = F\left(\frac{200 + 15c}{700 + 15c + c^2}\right)$$

P = safe load
l = length of column in inches
d = least diameter in inches
F = ultimate crushing strength of column in pounds per square inch
c = l/d
Factor of safety = 5

(Reference, *Engineering and Contracting*, July 27, 1910, p. 77.)

lower right-hand corner of the diagram, we find a stress of about 600 lb. per square inch for 2-in. plank sheeting, a figure probably not much exceeded, if at all.

"To use Fig. 104 with the same problem, entering the upper left-hand corner of the diagram with a depth of 21 ft. and a slope of 40° we find as before a pressure 500 lb. per square foot. Running along the horizontal line to its intersection with the inclined line in the upper right-hand corner of the diagram marked (by interpolation) '5 ft. 10 in. between wales,' we find a load of 2900 lb. per linear foot of wale at the given depth. Thence running down the vertical line representing 2900 lb. per linear foot of beam to its intersection with the inclined line in the lower right-hand part of the diagram marked 10 ft. between cross bracing, we find a bending moment of 350,000 in.-lb., assuming $M = 12wl^2/10$, also by interpolation we read about 29,000 lb. load on each cross-brace as a column. Running along the 350,000 lb. horizontal line to the lower left-hand corner of the diagram to 10 × 8-in. wales (outside the figure) we estimate 3200 lb. stress in the wale. Assuming as before that the horizontal earth pressure will not be developed by one-fourth and by going through the same process as outlined above we find a stress of 800 lb. per square inch in the wale, a figure probably not exceeded. It is of course obvious from the equation of $f = 3wl^2/2bh^2$ that the stress in the extreme fiber is directly proportional to w, hence we might have divided the high stress found from the theoretical earth pressure by 4.

"Table 50 is a table of resisting moments in wooden beams of various sizes and Table 51 gives safe loads on wooden posts, as developed from the formula of the U. S. Department of Agriculture, Bureau of Forestry."

CHAPTER XI

PURCHASING, HANDLING AND LAYING SEWER PIPE

Pipe should be purchased under carefully prepared specifications. The price of sewer pipe is governed by standard list prices, Table 52, from which varying discounts are allowed at different times and by different dealers. The basic discount adopted by the eastern manufacturers for standard 2-ft. lengths of pipe, from which others are computed, is 75 per cent.; 2 per cent. additional, or 77 per cent. total discount, is allowed if the purchaser accepts the pipe as delivered and stands the losses due to defective quality and breakage. On large work, if the pipe is bought subject to inspection, the pipe companies often prefer to have the inspection done at the mill before shipment, in order to save the losses due to reshipment of rejected pipe. For this purpose they sometimes prefer to maintain an inspector at the mill at their own expense during the manufacture and shipment of pipe. Cities of considerable size, which are large regular customers of pipe companies, often find that it is more economical for them to buy pipe as delivered, thus receiving the 2 per cent. additional discount, than to buy pipe subject to inspection. The difference between 75 and 77 per cent. off this list amounts to about 8 per cent. of the cost of the pipe at 75 per cent. off the list. Therefore, to make this plan economical, the losses due to breakage and inspection must fall within this 8 per cent.

While it may be possible to take advantage of this additional discount when dealing with pipe companies known to be absolutely trustworthy and capable of turning out satisfactory pipe, and thus save money under the 2 per cent. rule, it is hazardous to assume that this can be done in all cases, especially when dealing with untried manufacturers. It is seldom safe to attempt this saving when lots of only one or a few carloads are required, as occasionally large portions of a carload are broken or it is necessary to reject most of a carload of pipe. Thus the losses due to breakage and bad quality of one or a few carloads may often run so high that they cannot be brought within the 8 per cent. limit when averaged with all the pipe used on the job. Where a contract is very large, losses due to these causes ought to average well within this amount.

Pipe should be inspected on the cars as it is being unloaded. Technically a car will not be delivered by the railroad company until the receipt for it is signed by the consignee, the railroad at the same time having a rule that any claims for damage must be made at the time of delivery. This technicality is rarely insisted upon by a railroad agent, for it is impossible to inspect the pipe until one is allowed to enter and unload the car and look over its contents. Before the receipt is signed, it is advisable to show the freight agent the memorandum of broken and cracked pipe, a copy of which should then be attached to the receipt and the latter returned to the railroad. This may save future correspondence and even disputes. An average carload of from 12 to 15 tons of 3-in. pipe contains about 3500 ft. of pipe, 4-in. 3000 ft., 5-in. 2000 ft., 6-in. 1700 ft., 8-in. 1100 ft., 9-in. 1000 ft., 10-in. 700 ft., 12-in. 600 ft., 15-in. 450 ft., 18-in. 310 ft., 20-in. 234 ft., 22-in. 190 ft., and 24-in. 160 ft. If a car has evidently received bad usage in its passage over the railroad, its condition should be at once called to the freight agent's attention before the receipt is signed, and its condition noted thereon. As a rule breakage exceeding 5 per cent. of a carload is due to careless handling of the car by the railroad company, and the cost of the damaged pipe may be recovered.

Pipe Prices.—Pipe may be bought in 2, 2-1/2 or 3-ft. lengths. The 3-ft. lengths, based on the standard 75 per cent. discount, cost about 3-1/2 per cent. more than the 2-ft. lengths. From the standpoint of the workmanship and the number of joints, and the consequent problem of leakage, 3-ft. lengths are much to be desired, their extra cost being more than compensated for by the lessened number of joints. On the other hand, the manufacturers unquestionably have somewhat greater difficulties in delivering pipe of this length, of uniformly satisfactory quality, because of the tendency toward warping, and there are also somewhat greater possibilities of breakage.

There were three standard price lists for standard, double-strength and deep and wide socket pipe in the United States in 1913. These were known as the eastern, western and southern lists respectively. The first was used east of the Illinois-Indiana boundary and north of the Ohio River. The southern list applied to all states south of the eastern district and to Louisiana and Texas. There are now (1914) two western lists, the old and the new. Manufacturers at St. Louis, Kansas City, Denver and other western points are using the old list and those in Illinois, Minnesota and Iowa the new list. While the list prices in the new western schedule are much lower than those of the old schedule the discounts bring the net prices about the same.

The manufacturers of vitrified sewer pipe issue from time to time discount sheets based on the standard list. For example, an engineer in the eastern district in 1912 would receive quotations in the following general form: The basic discount from the eastern list for 1912 for standard, straight pipe 3 to 24 in. in diameter, in 2-ft. lengths and carload lots, f. o. b. Boston or other New England shipping point, the purchaser to stand losses from breakage and inspection, would be, say, 75 per cent. The discounts on other classes of pipe than standard, when the standard is sold at 75 per cent. off, are given in Table 53. If the current discount on the standard was higher or lower than 75 per cent., the tabulated figures would be increased or decreased by the number of points which the current discount is higher or lower than 75 per cent. The same discounts apply to the list prices for slants, branches and other specials. When the manufacturer stands the losses due to breakage and inspection, the discounts are decreased uniformly 2 points. For cash payment in 15 days, 2 per cent. may be deducted from the bill after paying freight charges. It should be repeated, these discounts are given merely as illustrations of the use made of the table.

Inspection.—Vitrified clay pipe should be carefully inspected to make sure that it is of the quality required by the specifications and which the manufacturer agreed to furnish. Some manufacturers are sufficiently careful with their mill inspection of shipments to prevent a material number of rejections by the consignee on account of inferior quality. If this is not the case, it is usually better for both parties if the consignee sends an inspector to the factory to inspect the pipe as loaded.

Inspection usually consists of "ringing" the pipe with a light hammer to see that it is not cracked, and carefully looking it over to see that it is

TABLE 52.—STANDARD LIST PRICES OF SEWER PIPE AND SPECIALS IN THE UNITED STATES, IN FORCE SEPTEMBER, 1919

Inside diameter, inches	Straight pipe; per foot			Curves; each Eastern	Elbows, each Eastern	Curves and elbows; each	
	Eastern	Western	Southern			Western	Southern
3	$0.30	.	.	$1.20	$1.20		
4	0.30	$0.12	$0.20	1.20	1.20	$0.48	$0.65
5	0.45			1.80	1.80		
6	0.45	0.18	0.30	1.80	1.80	0.72	1.10
8	0.70	0.25	0.50	2.80	2.80	1.00	2.00
9	1.05	.	.	4.20	4.20		
10	1.05	0.35	0.65	4.20	4.20	1.40	2.75
12	1.35	0.45	0.85	5.40	5.40	1.80	3.50
15	1.80	0.65	1.25	7.20	14.40	5.20	4.75
18	2.50	0.85	1.70	10.00	20.00	6.80	6.50
20	3.00	...	..	12.00	24.00		
21	..	1.15	2.50	.		9.20	8.25*
22	4.00	...	..	16.00	32.00		
24	4.50	1.50	3.25	18.00	36.00	12.00	11.00*
27	6.50	...	4.25	26.00	52.00		
30	7.20	.	5.50	28.80	57.60		
33	9.00		6.25	36.00	72.00		
36	10.25	...	7.00	41.00	82.00		

* Curves each

TABLE 52.—STANDARD LIST PRICES OF SEWER PIPE AND SPECIALS IN THE UNITED STATES, IN FORCE SEPTEMBER, 1919 —(*Continued*)

Eastern List	Y OR T BRANCHES		
Diameter, inches	Length, inches	Inlets, length, inches	Multiply price per foot of straight pipe of same diameter by
3 to 24	12 to 24	12 or less	4
3 to 36	30 or 36	12 or less	5
15 to 24	30 and 36	15 or more	7
27 to 36	30 and 36	15 or more	6
	DOUBLE JUNCTIONS		
3 to 24	24	12 or less	5
3 to 36	REDUCERS AND INCREASERS		4
3 to 36 SLANTS (two feet or less measured on long side)			4
Western List	Y OR T JUNCTIONS		
4 and 6	24		4
8	30		4 + 13¢
10	30		4 + 18¢
12	30		4 + 23¢
15	30		4 + 33¢
18	30		4 + 43¢
21	30		4 + 58¢
24	30		4 + 75¢
	DOUBLE JUNCTIONS		
	24		6
	30		6½
	JUNCTIONS WITH INLETS 15 IN. AND LARGER		
	24 30	Add 56 per cent. to list prices of junctions	
	INCREASERS, DECREASERS AND SLANTS		4
Southern List	Y OR T JUNCTIONS		
4	24		4 + 10¢
6	24		4 + 15¢
8 to 24	30		5
	DOUBLE JUNCTIONS		
	50 per cent. more than single junctions		
	INCREASERS AND REDUCERS		4

TABLE 53.—TYPICAL DISCOUNTS FROM SEWER LIST PRICES, IN FORCE SEPTEMBER, 1919

Diameter, inches	Standard pipe		Double strength with deep and wide socket	
	2 ft.	2½ or 3 ft	2 ft	2½ or 3 ft
3 to 24	69%	67%		
15 to 24		...	61%	59%
27 to 30	66%	66%	57%	57%
33 to 36	64%	64%	55%	55%

not excessively warped or deformed, that the bell and spigot ends are well formed and that it otherwise conforms to the specifications. An experienced inspector with an accurate ear can ring and examine pipe very rapidly, usually as fast as the pipe can be loaded on or unloaded from the car. For inspection, the pipe should be stood on end, preferably the bell end, on the floor of the car. A single light tap of the hammer will then instantly disclose a crack if any exists, although it may be practically impossible to see it. If, for any reason, it is necessary to find the crack, this can usually be done by rubbing the inside with a piece of white chalk, afterward wiping the chalk around and at the same time tapping the pipe lightly with the hammer. The crack will then be easily visible, filled with white chalk. Many a dispute has been settled in this way, without any harsh words. A record should be kept of the number of pieces of pipe and specials of each size in each car received and of the number rejected and the reason for the rejections. The blank form used for this purpose should have spaces to receive the number of the car, as "57203 P. R. R.," the general title of its contents, as "8-in. Akron pipe," the location where the car was set, as "yard," the date and time of the receipt and the complete unloading of the car, the name of the teamster taking away the pipe, a complete list of the contents as billed, a statement of the place of their delivery, a complete record of the rejections, the name of the man accepting the record and the data of acceptance, the railroad from which the shipment was received, and the date the records were received at the head office of the sewer department.

Inspection at the factory cannot wholly take the place of inspection at the point of unloading, and in fact the only way to be sure that cracked pipe do not find their way into the trenches is to inspect them on the ground just as they are about to be laid.

Tests.—In Illinois, Iowa, and other states where a large amount of cement pipe is used annually, attention has been given to testing pipe as delivered, and several inexpensive and light machines have been devised for such work. One was designed under the direction of Prof. A. N. Talbot which has a wood frame and can be moved readily from place to place along the trench, if the pipes are cast on the job and must be tested there. A lever having a 1 : 10 leverage extends out from the frame and its end is gradually loaded with known weights until the pipe is broken. The pipe is held at the bottom on two narrow supports about 2 in. apart and the load is applied along a single line at the top. The difference in bending moments when the pipe has a single support at the bottom or two supports close together is so small that Professor Talbot regards it as unimportant in most practical work. C. W. Boynton, testing engineer of the Universal Portland Cement Co., designed a machine for field testing which consists of a frame carrying a screw operated through gears by a hand-wheel. The pipe is placed between a horizontal chock on the lower end of the screw and a chair resting on a platform scale supported by the bottom of the frame carrying the screw. The chair has two half-round irons 2 in. apart on which the pipe rests. The chock has a half-round through which the load is applied to the top of the pipe. When the pipe has been placed on the chair the scale beam is balanced; on the end of the beam is a bucket into which water is admitted from a tank on the top of the frame as the load is applied by the hand-wheel.

Where the Iowa pipe specifications are in force, which require the load to be applied to the top quadrant of the pipe and the support to extend around the bottom quadrant, the tests are made by machines designed under the direction of Prof. A. Marston, of Ames, Iowa, who will supply detailed blue-prints from which any good mechanic can make one. There are three sizes of these machines. The Ames Junior is for pipe up to 18 in. and in it the load is applied and the pipe is supported by sand boxes. Above the upper sandbox is a jackscrew capable of loading the pipe with a total pressure of 6000 lb., which is as much as the ordinary scales on which the lower sandbox rests will carry safely. The Ames Senior machine is the size recommended for testing large pipe where the apparatus must be shifted. The pressure exerted by the jackscrew is transmitted through a lever to platform scales and the reduction in pressure due to the leverage has enabled the machine to be used successfully in testing pipe requiring a load of 24,000 lb. to break them. The Ames Standard machine has the same capacity but is not portable.

The tests made under the Iowa specifications are as follows:

Absorption Test.—1. The specimens shall be approximately 3 in. square, and shall extend the full thickness of the pipe wall, with the outer skins unbroken.

2. Five individual tests shall constitute a standard test, the average of the five and the result for each specimen being given in the report of the test.

3. Each specimen shall be dried in an oven, or by other application of artificial heat, until it ceases to lose further appreciable amounts of moisture when repeatedly weighed.

4. All surfaces of the specimens shall be brushed with a stiff brush before weighing the first time.

5. The specimens shall be weighed immediately before immersion, on a balance or scales capable of accurately indicating the weight within 0.1 per cent.

6. The water employed shall be pure soft water, at the air temperature of a room which is artificially heated in cold seasons of the year.

7. The specimens shall be completely immersed in water for a period of 24 hours.

8. Immediately upon being removed from the water, the specimens shall be dried by pressing against them a soft cloth or a piece of blotting paper. There shall be no rubbing or brushing of the specimen. The reweighing shall be done immediately with a balance or scales capable of accurately indicating the weight within 0.1 per cent.

9. The result of each absorption test shall be calculated by taking the difference between the initial dry weight and the final weight, and dividing the remainder by the initial dry weight.

Tests of Bearing Strength.—1. The specimens shall be unbroken, full-sized samples of the pipe to be tested. They shall be carefully selected so as to represent fairly the quality of the pipe.

2. Five individual tests shall constitute a standard test, the average of the five and the result for each specimen being given in the report of the test.

3. The specimens shall be dried by keeping them in a warm, dry room for a period of at least two days prior to the test.

4. Each dried specimen shall be weighed on reliable scales just prior to the test.

5. Each specimen shall be accurately marked, with pencil or crayon lines, in quarters, prior to the test. Specimens shall be carefully bedded above and below in sand for the one-fourth circumference of the pipe, measured on the middle line of the pipe wall. The depth of bedding above and below the pipe at the thinnest point shall be equal to one-fourth the diameter of the pipe, measured between the middle lines of the pipe walls.

6. The top bearing frame shall not be allowed to come in contact with the pipe or with the test load. The upper surface of the sand in the top bearing shall be carefully struck level with a straight edge, and shall be carefully covered with a heavy, rigid top bearing, with lower surface a true plane, made of heavy timbers or other rigid material capable of uniformly distributing the test load without appreciable bending. The test load shall be applied at the exact center of this top bearing in such a way (either by the use of a spherical bearing, or by the use of two rollers at right angles) as to leave the bearing free to move in both directions. In case the test is made without the use of a machine, and by piling on weight, the weight may be piled directly on a platform resting on the top bearing; provided, however, that the weight is piled in such a way as to insure uniform distribution of the load over the top surface of the sand.

7. The frames for the top and bottom bearings shall be composed of timbers so heavy as to avoid appreciable bending by the side pressure of the sand. The frames shall be dressed on their interior surfaces. No frames shall come in contact with the pipe during the test. A strip of soft cloth may be attached to the inside of the upper frame on each side along the lower edge to prevent the escape of sand between the frame and the pipe.

8. The sand used for bending the pipe at top and bottom shall be washed sand which has passed a No. 8 screen. It shall be dried by keeping it spread out thin in a warm, dry room.

9. The test load shall be applied gradually and without shock or disturbance of the pipe. The application of the load shall be carried on continuously, and the pipe shall not be allowed to stand any considerable length of time under a load smaller than the breaking load.

10. The total breaking load shall be taken as equal to the total top load, including the applied load, weight of top frame, sand for top bearing, top bearing timbers, etc., plus five-eighths of the weight of the pipe. This total load shall be divided by the length of the pipe in feet so as to give the

bearing strength per linear foot of pipe. In testing sewer pipe the bells shall be bedded and loaded, as well as the body of the pipe, and the length over all should be used in computing the bearing strength per linear foot.

The Modulus of Rupture.—The modulus of rupture of drain tile and sewer pipe shall be computed by the following rule: Divide the bearing strength in pounds per linear foot by 12, and multiply by the radius in inches, measured to the center line of the pipe wall; then divide this product by the square of the top or bottom thickness of the pipe wall in inches. The quotient will be the modulus of rupture, in pounds per square inch. The average thickness of the pipe wall shall be carefully measured at the top of the pipe, and also at the bottom, and the smaller of the two average thicknesses shall be used in the computations.

The absorption and breaking loads of vitrified clay and cement pipe tested by the Iowa methods are given in Volume I.

The tests of sewer pipe made by the Brooklyn Bureau of Sewers are carried out in a 75,000-lb. Riehlé crushing machine large enough to receive a 48-in. pipe. The pipe is not bedded in sand, which the Bureau believes increases the effect of the bell on the total breaking strength to a maximum. According to G T. Hammond (Proc. Am. Soc. Test. Mat., xi, 852), "the bell adds to the strength of the bell-end of a pipe exposed to a crushing load and the effect will vary with the length of the barrel of the pipe and also with the various conditions involved in the test. The effect is greatest on short lengths of pipe; thus, a 24-in. length of pipe with a bell will give a higher crushing load per foot than will a 36-in. length with a bell, the barrel portion of which is of equally strong material. Again, a pipe without a bell will break under a lower crushing load than a pipe of the same size of no better and no stronger material provided with a bell." The load is applied, in the Brooklyn tests, through a strip of plaster of Paris 1 in. wide, placed on the pipe between two wooden strips, into which the "knife" fits and into which it is put while the plaster is soft. The wood strips are removed before the test begins. · The barrel, but not the bell, of the pipe rests on a bed of sand which appears to develop a reaction over about 10 deg. of the circumference of the section. There has been some talk of abandoning this method of support in favor of a knife edge at the bottom as well as the top, not only because this is believed to give the greatest uniformity in the results but also because the unit strength of the material can be more easily and exactly determined from the test results.

At Kansas City, Mo., both cement and clay pipe are regularly tested (1913) to determine if they comply with these requirements:

Hydrostatic test: Untreated pipe shall show no percolation up to 10 lb. pressure and shall resist fracture at 33 lb. pressure per square inch.

Crushing test: When supported on a bed of sand, so that an even bearing is provided throughout the length of the pipe, the various sizes of pipe shall withstand the following pressures in pounds per linear foot applied at the crown uniformly along a line 1 in. wide and extending the whole length of the pipe exclusive of the bell:

Size, inches.......	6–8	9	10	12	15	18	21	24
Pressures, pounds.	1000	1050	1100	1150	1300	1450	1700	2000

The hydrostatic test is conducted in an apparatus designed to prevent any other pressures being exerted on the interior of the pipe than those normal to the shell. In the apparatus first used there was some doubt whether rupture was caused by true water pressure on the shell or by a wedge action of the head used for closing the bell. In the improved apparatus both ends are closed by heavy rubber cups held in place by a frame, described in *Engineering News*, March 20, 1913.

HANDLING AND STORING PIPE

It is a waste of money to inspect pipe and then by careless handling run the risk of breakage before they are finally laid in the trenches. Care should be taken in unloading and piling, and pipe should always be hauled in a vehicle provided with good springs. That the pipe are brittle and easily broken, should always be borne in mind by the men handling them. The men should be required to load the pipe carefully on the wagons, not only so as to reduce the danger of cracking them but also to insure full loads for teams. With a two-horse wagon having a body about 12 × 4 ft., 24 ft of 24-in. pipe will be a load, 33 to 45 ft. of 20 and 22-in., 60 to 66 ft. of 15-in., 90 ft. of 12-in., 114 ft. of 10-in., 150 ft. of 8-in., 225 ft. of 6-in. and 375 ft. of 4-in.

Pipe up to 24 in. in diameter are usually handled from the cars to wagons by hand. For sizes larger than this, which, however, are not much used at the present time, an ordinary guy derrick is convenient, although not absolutely necessary, as it is possible, by means of chutes, to handle the pipe by hand. Large cities should have yards for the storage of pipe and temporary yards may be desirable nearer work of any magnitude. The pipe should be stored in piles, the bells of one row alternating with the spigots of the next row on top, so that the different layers of pipe maintain a generally horizontal position. The ends of these piles must be sloped well back and blocked, so that there is no possibility of starting a run of the pipe in the lower rows, which would be disastrous to the whole pile. Branches and specials are stored in somewhat the same way, but it is usually necessary to place boards between the different rows, in order to preserve the stability and shape of the pile.

It is desirable to carry through the winter no more pipe than necessary, and such as is on hand should be so piled that there is no possibility of the lower pipes freezing into the ground or holding water which may freeze and thus cause breakage.

Pipe should not be stored on the job much in advance of the needs of the work being carried on. Where it is possible to store pipe in convenient yards, generally one or two days' supply on the job is all that is desirable, for in busy streets or about construction work there is a possibility of considerable breakage.

The pipe up to a diameter of 18 in. and possibly 24 in. are usually handled at the trench and lowered into it without the aid of machinery. A three-legged derrick, such as is used for lowering water pipe, is convenient, however, in the case of 24-in. and essential for larger sizes. A pipe-laying derrick mounted on a truck with wheels resting on a plank runway on each side of the trench is made by William Heggie, Joliet, Ill. (*Eng. News*, Feb. 20, 1913). For ordinary sizes of pipe a hook-rope is convenient, having a hook spliced in one end and a chain and hook spliced in the other. This chain is passed through the pipe and the hook fastened over the chain at the spigot end of the pipe, thus forming a loop in which the pipe hangs as it is lowered into the trench. Where some one of the jointing compounds is used, by which several pipe are put together on the bank, it is possible for two men to lower them into place, each one holding a rope looped over the pipe, one at either end, although it is better to pass a stiff rod through the pipe and attach a hook rope to each end, thus avoiding danger of the pipe sagging or breaking in the middle. The pole should have an eye in each end.

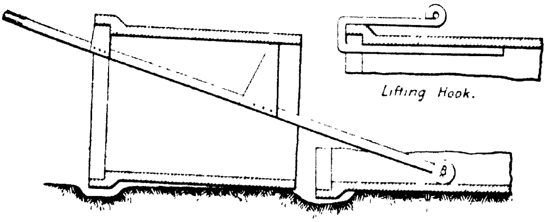


FIG. 106 Pipe buggy and lifting hook

After being lowered into the trench, the pipe is usually shoved into place by the pipe layer, his helper lifting the spigot end by means of a wire or strap passed under the pipe, although in this case, also, some mechanical devices may be desirable for the larger sizes. One of these devices, Fig. 106, consists of a long and strong hook by which the pipe may be lowered in a horizontal position, and the spigot inserted in the bell of the preceding pipe. Still another of these devices is the pipe buggy shown in the same illustration, which is handy in entering the spigot of one length into the bell of another.

The bottom of the trench should be brought as near as possible to subgrade, and a hole excavated at the place where the bell of the pipe will come, large enough to enable the workman to pass his hand under the pipe in order to calk the gasket into place and to fill the joint with cement, in case it is used. If, when the pipe is in place and tested for line and grade, it is found to be slightly too high, it is sometimes possible, by raising and pushing it down or lightly tapping it on top, to force it down to grade, but if it is much too high it is necessary to lift it up and scrape the earth out from underneath. If the bell of the pipe is found to be too low, the length should be removed and earth carefully shoveled and spread into place, in order to bring it up to grade. Pieces of rock or blocks or any supports of like character should never be placed under a vitrified or cement pipe in order to raise it to the proper grade, because they are rigid supports and when the trench is backfilled the pipe may be forced to act as a beam, which is a dangerous condition.

LAYING PIPE

For laying pipe of ordinary sizes, three or four men are required. One handles the pipe on the bank and lowers it into the trench; another receives the pipe and places it in position. He is followed by a third man, who makes the joint and carefully tamps the earth under and around the sides, filling the bell hole completely. The filling around the lower portion of the pipe should be placed uniformly on both sides of the pipe and care should be taken not to force the pipe out of position either horizontally or vertically. Where the work is being carried forward rapidly, this final operation may be done by a fourth man.

The head of the tamper used until the backfill is about a foot over the pipe should have a face not exceeding 1-1/2 × 5 in. nor weigh more than 7 lb. A tamper of even smaller size may be used to advantage until the filling is brought well up above the springing line of the pipe. Such a tamper may have a face about 4 in. long, a thickness of 1/2 in. and a handle made of 5/8-in. iron. The head should be canted slightly to aid in reaching the filling well under the pipe.

In ordinary stable ground the preparation of the trench for the pipe is a simple matter, and the bottom should be shaped as nearly as possible to fit the circumference of the pipe, bell-holes being excavated at the proper places. Where the trench is in rock it is generally specified that the bottom shall be excavated 6 in. below the grade of the invert of the sewer and the space refilled with gravel or fine material as a support for the pipe. There is some diversity of opinion as to the extent to which the trench must be prepared under these conditions. Some specifications require that the rock shall be everywhere at least 6 in. below the sewer, even to the extent of requiring that the rock under the bells *of pipes shall be blasted* out to greater depth than under the body of the pipes. Other specifications merely insist that the pipe shall have a uniform bearing.

The tests upon earth pressures made by Marston and Anderson, described in Volume I, indicate the desirability, when practicable, of narrowing the trench at the bottom by leaving earth shoulders on each side, at a level above the top of the sewer pipe, to increase the arching action of the backfilling and thus reduce the load or pressure upon the pipe due to it.

The greatest difficulties in laying sewer pipe are encountered in wet trenches. Under such conditions the water is usually carried away by means of underdrains. These are usually drain tile with open joints covered by strips of muslin and surrounded by coarse gravel laid in a subtrench dug in advance of the pipe laying, either to one side or directly under the line of the proposed sewer. The size of the drains is something to be determined by experience and judgment rather than by rule. These underdrains are seldom less than 4 in. in diameter or more than 8 in. Sometimes water enters so fast that it is impossible for it to find its way through the gravel into the underdrain, and in such cases it may be necessary to provide a small sump a short distance in advance of the pipe laying, from which the water may be constantly pumped, other sumps being dug farther along as the work progresses.

In very wet trenches in fine sand, the bottom sometimes boils up and resembles quicksand, and it becomes necessary to hold the bottom down by one means or another. Frequently gravel and coarse sand will be of some service; straw, brickbats, broken stone, cinders and like materials have all been used with more or less success from time to time. The best results are undoubtedly obtained when concrete is used in the bottom of the trench, but even this material sometimes is insufficient to hold down the boiling sand, and it is necessary to spread a platform of boards on the bottom of the trench before dumping concrete there. Where planks are used in this way they should be worked down through sand and water to at least 6 or 8 in. below the bottom of the sewer, and the water and sand cleaned off above them as thoroughly as possible before putting in the concrete.

In the very wet trenches of the Batavia, N. Y., sewerage system, for example, particular attention was paid to securing a rigid foundation, according to Charles Hoopes, Resident Engineer. The material below the invert was carefully watched, extra excavation and refilling with gravel were done when the soft material was shallow and sometimes when it was deep a concrete slab was put in below the invert. From 30 to 40 ft. were excavated ahead of the pipe each day to a depth of 9 to 12 in. below the invert, and a dry mixture of cement and gravel was rammed into the bottom of the trench to a grade which would be approximately 2 in. below the bell. The next day the pipe were laid on this slab by raising the grade with this same dry mixture, and after the pipe were at grade and jointed each pipe was rammed to the springing line with the mixture, and the trench was then backfilled with selected earth in the usual manner. In many places the earth pressure and the depth of soft material were so great that the pipe had a tendency to float. Then 7/8-in. boards 4 to 6 ft. long were nailed together, forming a lap at each seam, and driven as sheet piling to a depth of 2 to 4 ft. below the invert, depending upon the width of trench. Between these walls of sheet piling the concrete was deposited and pipe laid, this 7/8-in. sheeting being left in place. After two years no deflections appeared in sewers constructed in this manner even in the softest material (*Eng. Record*, Nov. 9, 1912).

The use of platforms under sewers is rather frequent and they may be built in various ways. Some engineers prefer a single plank laid directly under the sewer; this allows the water running over the bottom to pass along either side without undermining the sewer itself, but there is a possibility that this water may wash and cave in the sides of the trench. Other engineers prefer to build a cradle of timbers laid longitudinally a few inches apart, each length of pipe being supported by a transverse timber near each end, cut to conform to the shape of the pipe. By this method the water flows through the space left between the longitudinal timbers. On the other hand, there is a possibility that if an underdrain has been previously laid the water flowing directly under the sewer and over the underdrain may wash the material into the underdrain and cause the bottom to cave in, causing settlement of the sewer itself. There is also the danger of cracking the pipe on account of the possible lack of firm, uniformly distributed support below it.

In some kinds of material, particularly in quicksand, it may be almost impossible to carry the bottom of the trench down to the proper grade, without resort to various expedients. One of these consists of placing two planks on edge and far enough apart to include the pipe between them, thus forming a sort of bottomless box. The ends of these planks are fastened together in such a way as to keep them vertical, and they are then worked down into the quicksand to the bottom of the trench and secured there to the trench bracing. Planks cut of such a size as to form a bottom for this box are then put in place, one by one, men standing on each plank and working it down into place where it is fastened by cleats at either end.

A great deal of such work, however, may be obviated by careful handling of trench work, by accurate and rapid work doing away as far as possible with any unnecessary passage or walking over the material on the bottom by the men, for material of bad quality will sometimes stand up for a few minutes if not disturbed. A method of handling such work by draining out the ground water is described in an article by Leonard Metcalf in *Journ. Assoc. Eng. Socs.*, vol. xxiv, page 277. The drainage is usually done with driven wells.

The importance of proper supports for sewers is shown by the results of an investigation of the Hoboken sewerage system made in 1912 by James H. Fuertes. A large part of the city is quite flat, and the streets have generally been raised to their present elevation. There are large areas on which water stands throughout the year, lying from 1 to 3 ft. below the street levels and at about the mean high-tide elevation. The surface is a thin stratum of loose, porous material underlaid by soft muck or silt of great depth. All permanent structures, even one-story buildings, have to be placed on pile foundations. A large portion of the paved streets were much lower than the official grades, there being many intersections where the difference was 10 to 26 in. No information could be obtained concerning their elevations when first constructed. Owing to the boggy nature of the ground, the sewers, excepting those on a firm pile foundation, had settled out of line and grade so that, in some cases, their slopes were in directions the opposite of those originally laid out. In some cases sewage stood above the top of the sewer in the manholes and in a few cases appeared even in the catch basins at street corners. It was found, however, that most of the sewers placed on piles were in fairly good condition as to line and grade, and the fact that the pile foundation prevented a distortion of the sewers was shown by the presence of a large ridge in the street surfaces above the sewers, the street elsewhere having settled so much in some cases as to throw the fire hydrants far out of plumb.

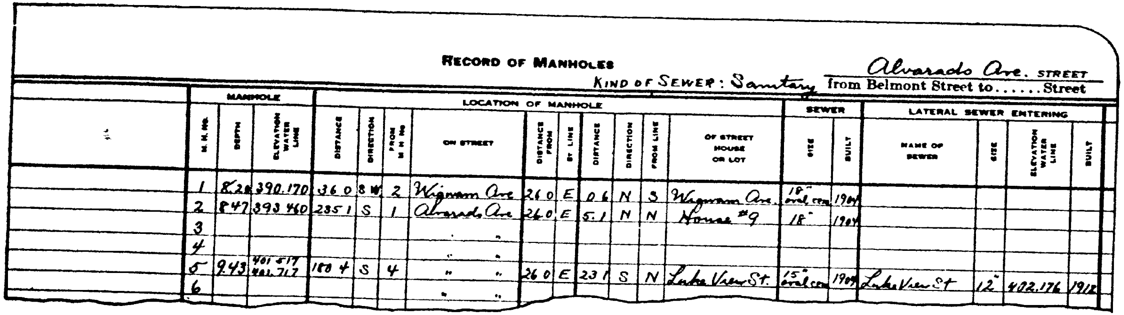
Branches.—A branch should be set in the sewer at every house. If the house is provided with plumbing, the engineer should go into the cellar and see where the main soil pipe leaves the building; the branch should be set slightly down the line of sewer from this point. If it is not possible to gain admission to the cellar, or if the house is not provided with plumbing, the engineer should decide on the proper location for the branch from the general appearance of the house. The branch should usually be set well down the sewer from the center line of the house and occasionally below the lower line of the house. Branches should also be provided for all vacant lots, the spacing depending upon the frontage of the lots. Where vacant land is not cut up into house lots the branches should be placed at frequent intervals, according to the general custom of laying out lots in the locality. The engineer should notify the foreman of the approximate location of the points at which branches are to be placed. The common practice is to have branches every 30 or 40 ft. on each side.

When the branches have been laid they should be referenced as described in detail on page 38. If possible the engineer should "locate" the branches before the trench is backfilled. If he is not on the work the foreman should be very careful to have a pole set at each branch before the backfilling is done. If poles long enough to reach to the surface of the street are not available, stakes may be driven opposite the branches, or laths may be tied to the tops of the poles. Great care should be taken to see that stakes are driven or poles set on the same side of the trench as the branch. In measuring up after the backfilling is completed, the engineer must be careful to make an accurate record as to whether the branch leaves the sewer on the right or the left.

A convenient method of recording the location of manholes is to refer them to the next lower manhole. For example, the first manhole at the lower end of the street should be numbered 1, and the successive manholes numbered consecutively, as 1, 2, 3, etc. The first manhole will be located from the street lines in both directions, as shown in Fig. 107, from a Worcester record. The first has a depth of 8.20 ft. and its water line is at El. 390.17. It is 36 ft. southwest of manhole 2 on Wigwam Ave., 26 ft. from the east street line, and 0.6 ft. north from the south line of Wigwam Ave. The sewer has an 18-in. oval concrete section and was built in 1904. The fifth manhole is 9.43 ft. deep and its water line is at El. 401.717. It is 180.4 ft. south from manhole 4 on Alvarado Ave., 26 ft. from the east side of the avenue, and 23.1 ft. south from the north line of Lake View St. The sewer in Alvarado Ave. at manhole 5 is a 15-in. oval cement section built in 1904, and is joined at the manhole by a 12-in. lateral sewer laid in Lake View St. in 1912. The branches for house connections are recorded as shown in Fig. 108. This shows that there is a 6-in. branch on the west side of the sanitary sewer opposite a vacant lot, at 20.6 ft. south from manhole 1 and 27 ft. from the east street line. There is also a 6-in. branch on the east side of the sewer opposite house No. 33; it is 77 ft. south of manhole 1, 23 ft. from the east street line, and 13.4 ft. south from the north line of the house. Both sets of records are kept in Kalamazoo loose-leaf binders on sheets measuring about 12-1/2 × 18-1/4 in. One set of manhole records or two sets of branch records can be kept on a page.

The branches are provided with stoppers to close the side outlets until such time as the connection is desired. These stoppers should be put in place before the branch is lowered into the trench, and should be made as nearly water-tight as possible.

In Worcester, Mass., the stoppers are inserted at the yard before the branches are carried to the work. This is done by placing a number of Y's on a specially designed horse, so that the branch openings are in a horizontal plane. The stoppers are then placed in position, jute is calked around them, Fig. 109, and considerable cement is placed around and over the jute and stopper. Then a piece of wood, cut in the form of

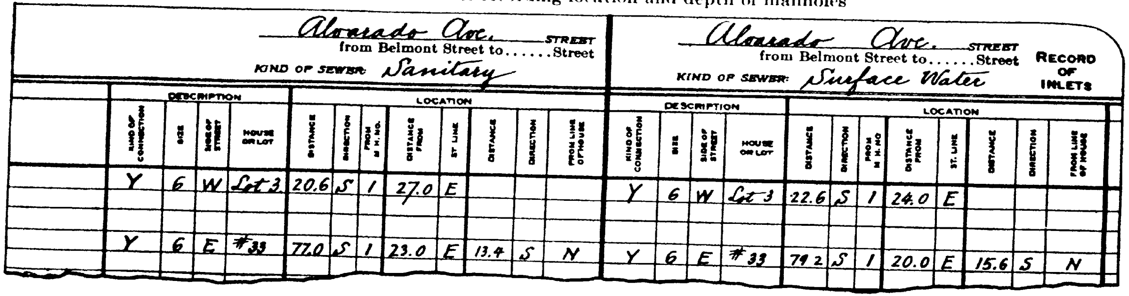


RECORD OF MANHOLES

Alvarado Ave. STREET
KIND OF SEWER: Sanitary from Belmont Street to......Street

MANHOLE			LOCATION OF MANHOLE										SEWER		LATERAL SEWER ENTERING			
M. H. No.	DEPTH	ELEVATION WATER LINE	DISTANCE	DIRECTION	FROM M H No	ON STREET	DISTANCE FROM	ST LINE	DISTANCE	DIRECTION	FROM LINE	OF STREET HOUSE OR LOT	SIZE	BUILT	NAME OF SEWER	SIZE	ELEVATION WATER LINE	BUILT
1	8.20	390.170	36.0	SW	2	Wigwam Ave	26.0	E	0.6	N	S	Wigwam Ave.	18" oval con	1904				
2	8.47	393.460	235.1	S	1	Alvarado Ave	26.0	E	5.1	N	N	House #9	18"	1904				
3						" "												
4						" "												
5	9.43	401.517 401.717	180.4	S	4	" "	26.0	E	23.1	S	N	Lake View St.	15" oval con	1909	Lake View St	12"	402.176	1912
6						" "												

FIG 107—Method of recording location and depth of manholes



Alvarado Ave. STREET
from Belmont Street to......Street
KIND OF SEWER: Sanitary

DESCRIPTION				LOCATION							
KIND OF CONNECTION	SIZE	SIDE OF STREET	HOUSE OR LOT	DISTANCE	DIRECTION	FROM M. H. NO.	DISTANCE FROM	ST LINE	DISTANCE	DIRECTION	FROM LINE OF HOUSE
Y	6	W	Lot 3	20.6	S	1	27.0	E			
Y	6	E	#33	77.0	S	1	23.0	E	13.4	S	N

Alvarado Ave. STREET
from Belmont Street to......Street
KIND OF SEWER: Surface Water

RECORD OF INLETS

DESCRIPTION				LOCATION							
KIND OF CONNECTION	SIZE	SIDE OF STREET	HOUSE OR LOT	DISTANCE	DIRECTION	FROM M. H. NO	DISTANCE FROM	ST. LINE	DISTANCE	DIRECTION	FROM LINE OF HOUSE
Y	6	W	Lot 3	22.6	S	1	24.0	E			
Y	6	E	#33	79.2	S	1	20.0	E	15.6	S	N

FIG 108.—Method of recording location of branches.

a truncated cone, is twisted around on top of the stopper. This forces the cement to the outside, forms a circular ring of cement in and over the joint, and leaves the central part of the stopper clean. Afterward, when it is desired to make a connection with one of the branches, it is necessary only to break the central part of the stopper with a hammer. It is then easy to chip out the remainder of the stopper and the mortar joint with a cold chisel. A generous quantity of jute should be used in making the joint, so that the cement will not fill too large a portion of the space between the stopper and the bell of the branch.

Branches stoppered in this way have been tested on many occasions and have been found free from leakage. It is a great advantage to put in the stoppers either in the store yard before the branches are shipped to the job, or upon the bank before they are put into the trench, as they are then much more easily accessible than they are after being laid. One man can put in about 100 of these stoppers in a day of 8 hours.

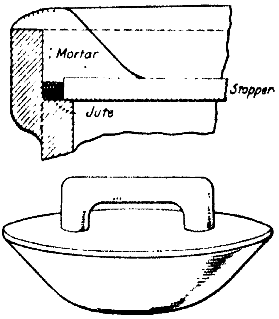


Fig. 109.—Stopper in branch and former for sealing it

Iowa Pipe-laying Requirements.—The requirements of the state drainage and engineering associations of Iowa for laying pipe in that state are based on the results of the investigation outlined in Volume I under sewer pipe, and are so unusual that they must be considered by themselves. The specifications issued in 1913 provide that no drain tile or sewer pipe not strengthened by bedding in concrete may be used in any part of a ditch where the average bearing strength of the pipe, as determined by the Iowa standard tests, is not equal, in addition to the weight of the pipes themselves, to at least 165 per cent. of the ordinary maximum load on pipe in ditches, as given in Volume I. Drain tile and sewer pipe having a lower bearing strength than that required, if used, must be strengthened by bedding in concrete. No sewer pipe may be used having a bearing strength less than 1250 lb. per linear foot for sizes under 15 in., 1500 lb. per linear foot for 15 to 20-in. pipe, 1900 lb. for 21 to 27-in. pipe and 2400 lb. for 28 to 36-in. pipe.

The average diameter of the pipe is not permitted to be 2 per cent. under the specified diameter. No two diameters are permitted to differ from each other more than 5 per cent. Adjacent pipe must match truly, which must be tested on the bank before the pipe are lowered into the ditch.

In all ordinary pipe laying in large sewers, the contractor is required to shape the bottom of the ditch approximately to fit the lowest 90 deg. of the circumference of the pipe, taking pains to secure an extra firm bearing near the outer edges of the 90-deg. strip. On the concave surface prepared in this way, a 1 to 2-in. layer of pulverized soil or sand, free from pebbles greater than 1/4 in., must be laid, and the pipe bedded firmly in it, truly to line and grade. Where the bottom of the trench is so wet and soft as to enable thorough bedding of the lowest 90 deg. of the pipe without the use of pulverized earth or sand and still is firm enough to afford a secure support to the pipe and the backfilling, the omission of the layer of earth or sand may be authorized, but this authorization will not excuse imperfections of bedding of the lowest 90 deg. of the pipe circumference.

The space between the pipe and the bottom and sides of the ditch must be completely packed full, by hand, with selected earth, and tamped with a light tamper as fast as placed, all up to the level of the top of the pipe. The side filling must be carried up as fast on one side of the pipe as on the other. The pipe must then be covered by hand with selected earth to a depth of at least 18 in. above the top of the pipe.

Whenever the factor of safety of the pipe, as calculated from the tests of strength and the tabulated load imposed by the backfilling, exceeds 2.5, the shaping of the bottom of the ditch to fit more than 45 deg. of the bottom of the pipe may be omitted, together with the bedding in an earth or sand layer and the special tamping of the side filling around the pipe.

In all parts of ditches in soil where the pipe must be strengthened to carry heavy loads, by bedding in concrete, the Iowa requirements call for work done substantially as follows: The bottom of the ditch must be shaped by the contractor to fit approximately the lowest 90 deg. of the pipe circumference. On the concave surface so prepared, the contractor must spread a layer of at least 2 in. of soft concrete stiff enough to sustain the weight of the pipe, and the pipe must be firmly bedded, truly to line and grade, in this concrete. The space between the pipe and the bottom and sides of the ditch must then be completely packed full of soft concrete up to a level 15 deg. of the pipe circumference above the mid-height. The thickness of the concrete must not at any point be less than 2 in., and it must be tamped in place with a light tamper. The concrete used in this method of strengthening pipe must be made of 1 part Portland cement and 8 parts gravel, or 1 part Portland cement, 5 parts sand and 8 parts broken stone.

In all parts of ditches in yielding soils, such as muck and quicksand, where the pipe must be strengthened to carry heavy loads, by bedding it in concrete, the Iowa specifications require the work to be done in the following manner: The bottom of the ditch is finished approximately level, with slightly rounded corners, and on this is spread a layer of soft concrete, the full width of the ditch, in which the pipe are firmly bedded truly to line and grade. The thickness of concrete below the lowest part of the body of the pipe is at least one-eighth of the inside diameter. Soft concrete is then built up on each side of the pipe, completely filling all the space under and up to it, up to a level on each side of the pipe about 15 deg. of the pipe circumference above the mid-height. The width of the concrete is such as to give a thickness on each side of the pipe at its mid-height of at least one-fifth of its inside diameter. The concrete is tamped with a light tamper, and is mixed in the proportion of 1 part Portland cement and 5 parts of gravel, or 1 part cement, 3 parts sand, and 5 parts broken stone.

BACKFILLING

One of the most important steps in the laying of pipe and masonry sewers is backfilling the material excavated from the trench. The pipe must be well supported on its lower surface and the earth should be thoroughly consolidated around the upper half.

The material for filling around the sewer, especially a pipe sewer, should be selected, and large stones or hard lumps of earth excluded. The fill should be carried up equally on both sides of the sewer and should be thoroughly rammed in thin layers as fast as it is thrown into the trench. For this purpose an iron rammer, having a face about 1/2 in. wide and about 4 in. long, with a 5/8-in. iron handle, is well adapted. The head of the rammer should be slightly canted to one side so that it may be readily forced in under the pipe. When the backfilling is brought up about to the springing line of the pipe and thoroughly tamped, a heavier and larger rammer may be used. This should be about 1-1/2 in. thick by 5 or 6 in. long, and have an iron handle of 3/4-in. gas pipe. This rammer should be used in filling a trench up to the top of the pipe.

The backfilling of the trench above this point is of much importance, because if not thoroughly done settlement is likely to take place. Only loose dirt should be placed around the pipe until the backfill is carried to a height of 6 to 12 in. above the crown of the pipe, or higher if filling is dumped from a height in large quantities, as from a bucket. Above this filling the coarser material may be used, but care should be taken to have rocks and lumps of hard material completely surrounded with fine material, so that there shall be no large voids. Usually one rammer to one or two men shoveling the earth into the trench, will accomplish satisfactory work.

With some kinds of material the backfilling may be consolidated by the use of water, the process being known as puddling. Water should usually not be put into the trench until the backfilling has been carried up a short distance above the top of the pipe; then the trench should be partly filled with water and the earth thrown into it. The use of water is particularly well adapted to materials through which the water can be readily drained away. Water should not be used in clayey materials which will hold it for a long period of time and which tend to shrink as the water dries out.

By thorough ramming it may be possible to put more earth into a trench than by puddling with water. With some classes of material, such as loam, it is possible to put more material back into the trench than came out of it, and with sizes of pipe up to 15 in. usually all such material taken out can be put back. With other material, such as gravel, clay and hardpan, there will be a surplus left after backfilling, in excess of the cubic space taken up by the pipe and manholes.

It is often desirable to fill the trench completely full of earth or even overfill it and then to roll it with a steam roller. If the trench is narrow this may best be done by so operating the roller that one of the rear wheels will pass over the trench and follow the backfilling down below the surface of the street. If sufficient material is put into and over the trench to completely fill it after rolling, it will be necessary to remove a portion of the surface to make room for the macadam or paving to be put back later. Where a roller is used it is important to take care not to hit the manholes, as the frames may be displaced and the brickwork injured.

It is generally possible and in most cases practicable to backfill a trench so that no settlement will be apparent on the street surface. In a loosely backfilled trench, however, settlement is almost sure to take place. If pavement is laid over such a fill the settlement may not take place for years. In some cases pavement has given way or has been taken up years after the sewer was laid, and the backfilling was found to have settled considerably, leaving large spaces between the soil and the bottom of the pavement, an unsafe condition because of the danger of the pavement breaking through under loaded vehicles.

Care should be taken when dumping backfilling into the trench from bucket machines or derricks that an excessive shock or load be not placed upon the structure. Filling so deposited should be spread sufficiently to fill all spaces in the trench.

In very deep and wide trenches it may sometimes be less expensive to repair the street after settlement than to go to the expense of very thorough tamping during construction. The engineer in drawing his specifications for the consolidation of backfilling must use judgment as to the expense to which he cares to go to have the backfilling tamped or puddled, basing his judgment upon the character of the work and the nature of the locality through which the sewer is to be built. Where it is not desired to spend sufficient money to thoroughly tamp the backfilling much can be accomplished with little labor by spreading the dirt to make sure that the voids around the stones and hard lumps of earth are filled. The use of water in puddling is generally less expensive than tamping and where it is not necessary to do thorough tamping, much can be accomplished by the judicious use of water. Upon some large work it is not practicable to fill the trench with water and throw the material into it. If this is impracticable considerable good can be done by the intelligent use of a stream of water from a hose.

The cost of backfilling may in part be offset by the saving in the amount of material to be hauled away. Where it is necessary to haul the surplus material a long distance, the cost of hauling may be fully as great as the cost of the tamping necessary to put the material back into the trench.

Backfilling should always be done as soon as possible after the sewer is built, in order to clean up the street and prevent inconvenience to the public due to large piles of dirt left in the street unnecessarily long. Where there is a surplus of material, the finer material and that which can be consolidated to best advantage should be used for backfilling, the coarser part being carried to the dump. In freezing weather it is sometimes difficult to get enough fine, unfrozen earth for backfilling immediately around the sewer. This should be done, however, even if necessary to thaw the earth thrown out upon the bank for the purpose. Filling the trench with frozen earth is always unsatisfactory and it is never possible to secure a well-compacted fill under such conditions. Settlement follows thawing in the spring, when further filling becomes necessary. Moreover, the integrity of the sewer pipe may be endangered by such practice.

Where it is not necessary to reopen the street to travel, as when the sewer is built through open fields, the amount of labor devoted to tamping may sometimes be reduced or wholly eliminated and the fill allowed to settle and become compacted by rains.

Tamping is a portion of the work which is very likely to be neglected. It is not excessively expensive and is usually well worth the cost, especially in city streets. The cost of tamping varies greatly, but in ordinary city trenches where the sewers are small, it may be done by from one tamper per shoveler, to one tamper to three shovelers, or say roughly from $0.15 to $0.05 per cubic yard.

Trench tamping machines are used in a few places for consolidating the backfill. In Wilmington, Del., for instance, the machine made by R. H. Staley is used. This has an 80-lb. steel head 8 in. square fixed to the end of a long vertical ram, which is raised and then allowed to fall by its own weight. The ram is lifted by a small gasoline engine driving a pair of cam wheels. These wheels butt against either side of the ram, which is fitted with wooden contact surfaces to allow the cams to hit and lift the rod with its 80-lb. weight. The cams rotate continuously in one direction, and when the solid part of the rim passes the wooden contact surface of the rod, there is nothing to sustain it and it falls upon the material to be consolidated. The machine strikes about 54 blows a minute. The vertical ram is mounted on a framework which can be swung through a horizontal arc, thereby covering the entire width of the trench at one setup. As the work progresses the tamper truck is moved forward on its own wheels.

Alexander J. Taylor, Chief Eng. of the Wilmington Street & Sewer Department, wrote to the authors on Dec. 10, 1913, regarding the machine as follows:

> "The results obtained from the use of this machine have been satisfactory to us. We have no definite data regarding the cost of its operation, but speaking in a general way it requires two men for its proper manipulation and propulsion along the trench. The amount of gasoline consumed has varied from 1 gallon for a run of 4 hours when the apparatus was new, to 5 quarts for the same length of time at present. Using as a basis of comparison a ditch in which the backfilling is handled by employing one man ramming to one man shoveling, I would say that the tamper will pack to the same degree of thoroughness earth thrown in by approximately six men. The degree of alertness and skill of the operator can increase or decrease this average. We have not had any trouble with the work done by the machine, which is equipped with a hammer reaching to a depth of 6 ft. Our sewers are built generally with the spring line 9 ft. below the surface of the street. It is our usual practice to hand-tamp the first 2 to 2-1/2 ft. of the backfilling before the machine tamper is put into operation. If necessary the hammer may be lengthened. We have made a number of examinations of terra cotta pipe laid in trenches backfilled in this manner, and have not yet found any broken places."

COST OF LAYING PIPE

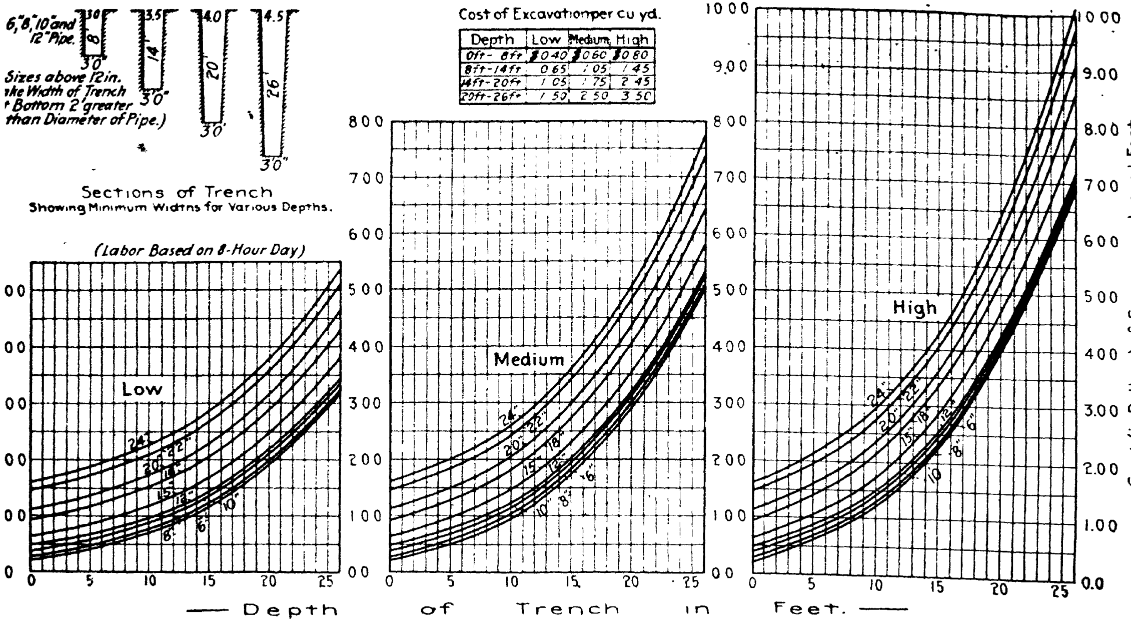
Conditions under which work is done are so variable that the cost of laying pipe on individual jobs is not of much general value. The exact items included are also not always clear; sometimes the cost of laying includes work of backfilling around and over the pipe, while in other cases it includes the laying alone. The curves of Fig. 110 are based in part on data in Table 54. The unit prices assumed in these data are those gained from general experience in this class of work, and the actual prices for different sizes of sewers and different depths of trenches are calculated from these unit prices. These curves were based on the use of 3-ft. lengths of pipe. In this connection it may be said that the cost of similar work with 2-1/2-ft. lengths of pipe would be about 4 per cent. greater and with 2-ft. lengths of pipe about 8 per cent. greater. This calculation is based on the data given for the 12-in.

pipe and on the assumption that the only differences in cost are those due to the laying of the pipe and to the amount of cement and sand necessary on account of the different number of joints with the different lengths of pipe used. It is further assumed, although not exactly true, that the cost of laying applies entirely to the work on the joint, that is to say, with a 3-ft. length of pipe this amounts to 9 cents per foot; with a 2-1/2-ft. pipe to 10.8 cents; with a 2-ft. pipe to 13.5 cents per foot. With regard to the relative cost of the laying with different kinds of jointing material, it is almost impossible to give strictly comparable figures. It will be found that bids by experienced contractors are quite variable in this respect, some bids running higher for cement joints, for instance, than for joints of sulphur and sand. While the materials for special jointing, asphalt, sulphur and sand, G-K Compound, etc., cost more than cement, the ease with which joints may be made up with them on the bank and in the trench and the freedom from long-continued pumping in wet trenches, offset to a considerable extent the difference in the cost of the materials. This is particularly the case if the work is done under very rigid inspection and insistence placed on thoroughly well made joints. It should also be noted that the actual cost of pipe laying is but a small percentage of the total cost of the work, so that a few cents variation in this cost but slightly affects the total.

The diagrams given in Fig. 110 have been prepared to give the reader a general idea of the cost of constructing pipe sewers under ordinary conditions in easy, moderately hard, and hard digging. The cost of such work varies greatly from time to time, with the cost of labor, the length of day, the difficulties surrounding the work, as rains or freezing weather, and a multitude of other conditions. It is therefore obvious that these estimates of cost should not be applied too literally, but should be used only as a general guide.

If the engineer will compare the cost of all work of this sort coming under his attention with the "medium" scale as standard, obtaining the coefficient or relative cost of his work (the ratio of his cost to the medium scale cost), he will soon acquire such a knowledge of relative costs as it would be impossible to obtain otherwise. Under such procedure it matters little if the standard is too high or too low, provided it is a fairly consistent scale within itself and provided it is fixed, so that the engineer shall always use the same reference scale for his comparison.

Rate of Pipe Laying.—The rate of progress in pipe laying is usually dependent upon the rate of excavation of the trench. It is also more or less dependent upon the amount of excavation and backfilling required of the pipe-laying gang. For the smaller sizes of pipe, say from 8 to 15 in., two men are required in the bottom and one or two men on top, depending on the arrangement of the work and the rate of progress required. For 24-in. pipe two men will be required in the



Cost of Excavation per cu yd.

Depth	Low	Medium	High
0ft - 8ft	$0 40	$0 60	$0 80
8ft - 14ft	0 65	1 05	1 45
14ft - 20ft	1 05	1 75	2 45
20ft - 26ft	1 50	2 50	3 50

FIG 110.—Curves giving the cost of sewers under different conditions.

Trenches excavated by hand, with labor at 25 cents per hour

TABLE 54.—COST OF PIPE LAYING PER LINEAR FOOT

Item	Diameter of pipe in inches								
	6	8	10	12	15	18	20	22	24
Pipe:									
Deep and wide socket	$0.108	$0.148	$0.216	$0.270	$0.364	$0.608	$0.743	$0.990	$1.073
Standard	0.104	0.143	0.208	0.260	0.351	.....	.....	.....	.....
Branches and stoppers [1]									
Deep and wide socket	0.016	0.020	0.027	0.032	0.042	0.064	0.077	0.100	0.108
Standard	0.015	0.019	0.025	0.030	0.038	.....	.....	.....	.....
Loss, shipping and inspection	0.009	0.012	0.018	0.022	0.030	0.042	0.050	0.066	0.072
Hauling (1 mile) unloading, inspection and piling	0.009	0.012	0.018	0.024	0.039	0.047	0.059	0.072	0.095
Cement and sand:									
Deep and wide socket	0.005	0.007	0.009	0.010	0.016	0.017	0.022	0.027	0.030
Standard	0.002	0.004	0.004	0.005	0.006	.....	.....	.....	.....
Laying	0.045	0.060	0.075	0.090	0.112	0.135	0.150	0.165	0.180
Lights and watchman	0.009	0.009	0.010	0.011	0.013	0.015	0.018	0.023	0.023
Liability insurance—8 per cent. of labor	0.004	0.006	0.007	0.008	0.010	0.012	0.013	0.015	0.016
Total (excl. of excav.)—deep and wide socket pipe	$0.205	$0.274	$0.380	$0.467	$0.626	$0.940	$1.132	$1.458	$1.597
Standard pipe	0.197	0.265	0.365	0.450	0.599	.....	.....	.....	.....

[1] Includes setting.

Notes.—Curves in Fig. 110 are based on deep and wide socket pipe, 3-ft. lengths, for sizes 6 to 15 in. inclusive—for larger sizes double strength pipe 3-ft. lengths. Prices based on list price adopted by the Eastern manufacturers, May 2, 1912. Discounts correspond with basic discount of 75 per cent. on standard pipe, 2-ft. lengths. Loss due to shipping and inspection, 2 per cent. of list price. Two 6-in. branches 2 ft. long with stopper furnished and set every 40 ft. Cement at $1.50 per barrel; sand at $1.25 per cubic yard. Labor based on 8 hour day, wages $2 per c trench and two or three on the bank. The rate of progress will lie between the following limits:

8-in. pipe, 50 to 150 ft. per day of 8 hours
24-in. pipe, 20 to 60 ft. per day of 8 hours

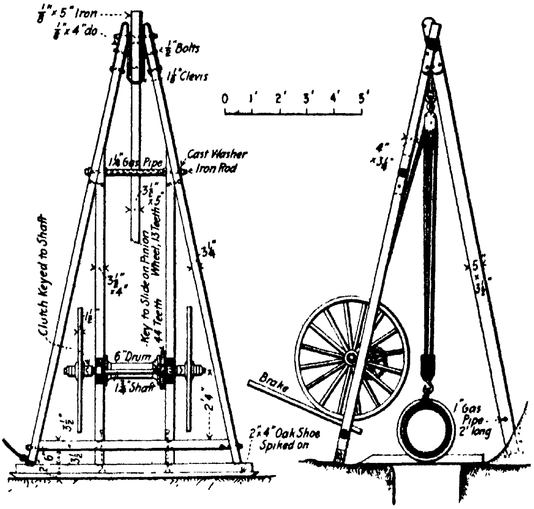
It must be remembered, however, that the rate of progress depends upon local conditions. In some cases it may be economical to make the rate of progress very slow and require considerable excavation and backfilling of the pipe-laying gang, while in other cases it may be wise to have them do very little excavation and backfilling and proceed more rapidly with the pipe laying. The engineer or foreman in charge of the work must be governed by the local conditions.

LAYING LARGE CONCRETE PIPE

Large concrete pipe are so heavy that special equipment for handling them is necessary. So far as practicable contractors generally endeavor to utilize in this way a locomotive crane which can be employed also in excavating the trench. For example, the contractor for about a mile of 6-1/2 and 7-ft. concrete pipe sewer laid in Detroit in 1910, took out the top 6 ft. of the trench, which was 11 ft. wide, with a Thew shovel. The remainder of the 16-ft. depth of trench was taken out with a 15-ton locomotive crane, and the bottom of the trench was shaped to a half circle, a little higher than the true grade, by hand. The pipe, which weighed about 6 tons each, were turned over on their sides, after the molds were removed, in order to be rolled to the trench; they were turned over at first by means of a gantry crane, with an I-beam top bar supporting a chain block hoist, and, later, by a tripod of steel pipe attached at the top to a short I-beam; the tripod proved more satisfactory than the gantry crane.

The pipe were rolled to the trench by teams. At the trench they were picked up by a specially designed saddle or hook having a large bearing on the inner surface of the pipe, which was hung from the boom of the locomotive crane. This saddle fitted below the top of the shell of the pipe as it rested on the bank, but when the pipe had been landed on the bottom of the trench it was customary to loosen the fall a little, lift the saddle somewhat to one side, and then tighten the fall just enough to roll the pipe over on its bed without changing its position laterally in the trench. In this way the weight of the pipe was made to consolidate the bed and secure a good bearing along the entire length of the bottom of the shell.

In the case of the Harbor Brook intercepting sewer at Syracuse, N. Y., built under the direction of Glenn D. Holmes in 1911, 42-in. Jackson concrete pipe were laid with a three-leg sulky derrick of the type used in handling large cast-iron pipe, Fig. 111. For laying 54-in. pipe the Reinforced Concrete Pipe Co. furnished the gantry crane shown in Fig. 112. In both parts of the work the pipe were laid on a concrete foundation supported by a single row of piles spaced 4 ft. apart on centers. After the joints had been cemented, the lower part of the trench was filled with concrete to give the pipe a bearing over a fourth of its circumference.



End Elevation. Side Elevation.

FIG. 111.—Sulky derrick for trench work

LAYING CAST-IRON PIPE

The handling and jointing of cast-iron pipe for sewers are conducted like similar work for water mains. Where curves are needed, some engineers allow as the maximum angle permissible in each joint that which is represented by pulling the spigot 3/4 in. back on one side; this is an angle of about 1 deg. Where this will not give the desired curvature, special castings must be used.

Large pipe are often laid on blocks (see Table 55) placed near each end of each length. These blocks are laid across the trench bottom and must be firmly supported, and the pipe are held on them by wedges. Smaller pipe are laid on the earth bottom, a hole being dug for the bell; it is not well to lay them directly on rock. The use of blocking is to be avoided where practicable on account of the danger of concentrating the external pressure on the pipe.

TABLE 55.—SUPPORTS FOR CAST-IRON PIPE (BOARD OF WATER SUPPLY, NEW YORK)

Size of pipe, inches	16–24	30–36	42	48
Blocking, inches	2 × 10 × 2½	3 × 10 × 3	3 × 10 × 3½	3 × 12 × 4
Wedges, inches	4 × 4 × 10	4 × 4 × 12	4 × 4 × 12	4 × 4 × 12

When two lengths of pipe are in place, jute packing is driven into the joint, leaving a space at least 2 in. deep for pipe under 12 in. in diameter, 2-1/2 in. deep for pipe from 12 to 24 in. in diameter, and 3 in. deep for larger sizes. The outside of this space is closed by a yarn and wet clay gasket or asbestos jointer, and melted lead is gradually poured into the enclosed space. Only one pouring should be made for each joint and dross should not be allowed to collect in the melting pot. This lead is then carefully calked with a hammer and tools made specially for the purpose, so as to give a tight joint without cracking the bell. Joints have been made on some water-works mains with pneumatic hammers, and a fibrous form of lead called "lead wool" has been used occasionally where it was undesirable to melt lead in the usual fashion. The lead wool was calked cold into the joints. Not enough experience with these methods has been had as yet (1913) to furnish definite

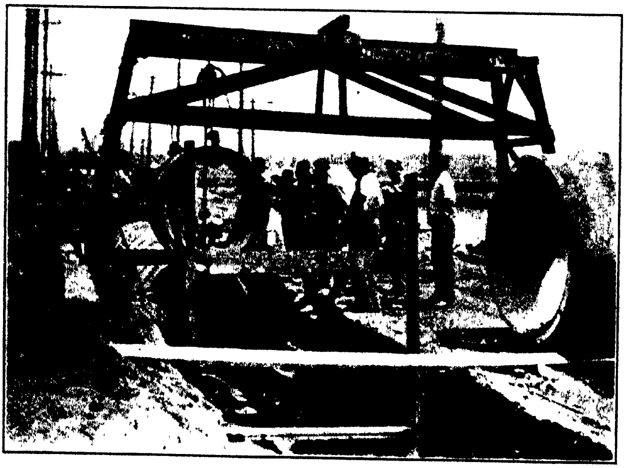


FIG. 112.—Laying 54-inch concrete pipe at Syracuse.

information concerning them. A soft lead pipe wrapped several times around the pipe and calked into the joint at the same time may also be used in wet trenches.

Pipe up to 8 in. in diameter can be lowered into the trench by a rope sling and man at each end. Larger sizes are best handled by a derrick spanning the trench, as shown in Fig. 111 (*Eng. News*, vol. xxxv, p. 339). The special advantage of this derrick and others of the same general type is that it can be readily moved on its own wheels, which are also of service in handling the pipe.

In what are known as solid lead joints, only one strand of yarn is used. The entire joint must be run at a single pouring and it is necessary with large pipe to calk the inside as well as the outside of the joint.

LAYING STEEL PIPE

The engineer is usually more apprehensive of injury of the pipe coating than of the pipe itself, although large pipe must be braced by interior struts to prevent their collapse. The contractor has sometimes been required to cushion all bearing surfaces on which the pipe rests with enough layers of burlap or other soft material to prevent scratching of the coating, and no uncushioned ropes, chains, levers or other handling devices were permitted in handling the pipe. On the Little River works of Springfield, Mass., a covering of canvas or equivalent material at least 30 in. wide was kept on top of the pipe in the trench until backfilling was in progress on the spot, and no person was permitted on the pipe without rubber or felt soles on his shoes. This was unusually severe. In other places it has been considered necessary merely to forbid persons having shoes with hob nails to walk on or in the pipe.

In a trench with sandy bottom, it is customary to place sand under the pipe at frequent intervals until it is securely in line and grade. In a rock trench or where the pipe is to be surrounded with concrete, it is usual to spread about 6 in. of sand over the rock.

The backfilling must be done with regard to avoiding injury to the pipe coating as well as to the pipe. The material in the lower part of the trench must be well tamped; the backfill on top of the pipe should begin in the middle of each length, leaving the field-riveted joint exposed until the test for tightness has been passed. A 5-ft. pipe should be braced on the inside during backfilling and when the braces are removed there should not be more than 3 in. difference between the horizontal and vertical diameter.

The laying of riveted steel pipe involves the handling of long heavy sections of pipe, and an attempt should be made in such cases to adopt a plant which can be used economically for other purposes than lowering pipe. In laying a 72-in. steel pipe sewer in Jersey City, for example, a locomotive crane was made to do double service, and thus keep down the machinery charge against each class of work. It was employed part of the time in excavating the trench 8-1/2 ft. wide, with a 1-yd. orange-peel bucket, and this was rather slow in hardpan, which was reached on a part of the work at a depth of 4 ft. This hardpan was loosened with picks, but even with this help the bucket was rarely full. Most of the excavated material was backfilled on the pipe within 50 ft. of the place where it was taken out, as an attempt was made to keep the length of open trench as short as possible. The main use of the locomotive crane was handling the 18-ft. 6-ton lengths of riveted pipe, which were first taken from a siding to a storage yard and then delivered as needed.

A riveted steel pipe line was laid in 1907 for the St. Louis water works, in a trench which averaged from 10 to 28 ft. in depth. The lengths of pipe were delivered along this trench by an electric railway operated by the city for delivering supplies to pumping stations nearby. The pipe were delivered in 28-ft. lengths and were handled into the trench, from the side of the railway where they had been delivered, by a stiff-legged derrick. Each length had a line attached around its center, a piece of rubber hose being threaded over the line to prevent any injury to the pipe coating. The riveting was done with pneumatic hammers supplied with air by two electrically driven compressors, which took their current from the transmission line of the electric railway. The whole equipment was very compact, and but little trench was kept open ahead of the pipe-laying, an advantage in this case because the banks of the trench stood readily with very little bracing. The excavation in the deeper parts of the trench was made by a 20-ton steam shovel, mounted on a platform which spanned the trench and could be rolled along plank runways about 3 ft. back from the top of each side of the excavation (*Eng. Record*, Sept. 7, 1907).

Riveted steel pipe are exposed to a special danger on account of their light weight in comparison with their diameter. In the case of a 48-in. steel main at Kansas City, Mo., for example, the contractor had a section of pipe 1500 ft. long broken in two after it had been riveted, but not backfilled, owing to a heavy rain that flooded the trench full in a few minutes, and lifted the middle of the pipe in a long vertical curve. After the pipe had been drained it was found that a vertical rise of over 2 ft. in the center of the pipe was held up by dirt which had settled below it. In a number of places the pipe rose in the bottom of the trench, owing to the rising of quicksand; this was remedied by loading the pipe as soon as it was coupled up.

SUBAQUEOUS PIPE LAYING

Subaqueous pipe laying is mainly required on sewerage work in connection with outfall sewers and inverted siphons. The first work is usually to provide a foundation for the pipe when laid. Sometimes this is a trestle formed by driving piles in the bed of a stream and then sawing them off at the proper height by means of a submerged circular saw. Sometimes wooden blocking at a few low points of the bottom will answer all purposes. Sometimes it is necessary to excavate a trench in rock, and when this is the case it may prove desirable to lay bare the site for the pipe, so far as practicable, by running a wing dam out from the shore, where there is sufficient current to make this method of getting at the bottom practicable. If the water is shoal for any distance a cofferdam may be run out and a trench excavated within it. As a rule, however, the usual methods of excavation under water are preferred by contractors, that is to say, they take out the soft material by orange-peel or clam-shell buckets or by small dipper dredges. Where rock has to be excavated, the holes for blasting are sometimes drilled by a percussion drill mounted on blocks held by vertical stays on the side of a scow, a method of mounting which has become standardized for drilling work of this nature for harbor improvements.

The pipe are laid in the water by one of three general methods: first, lowering the pipe line into the water from some kind of support; second, dragging it into place from launching chutes on shore or from scows, or, third, by floating it into place. The different methods are best explained by giving examples of each.

In some cases where the bottom of a stream is very soft so that dredging results in a very muddy condition of the water and considerable uncertainty exists as to what kind of trench is actually produced, submerged pipe laying has been carried on by means of a sand pump or water jet. At Michigan City, Ind., a 20-in. line was lowered about 4 ft. in this way and at Hammond, Ind., a 16-in. riveted pipe. Where this method is used the pipe is simply laid along the bottom, with the ends disconnected from the shore line, and the material under the pipe is gradually worked away by means of the pump, the current carrying away the silt which is disturbed in this process. The method is, of course, an expedient which is only rarely practised.

Laying Pipe from Supports.—On rare occasions submerged pipe lines can be put together on top of a sheet of ice and lowered through a long gash cut in it. This was done by E. C. Cooke at Escanaba, Mich. The pipe was 5 in. in diameter, about 2000 ft. long, of wrought iron with Converse lock joints. After the pipe was lowered to the bottom by means of rope slings passing over timbers laid across the hole in the ice, the material on the bottom under the pipe was excavated by means of a water jet, allowing the pipe to settle slowly.

At Austin, Minn., where 150 ft. of cast-iron pipe were laid across a river in the winter of 1911-12, the contractor, the J. W. Turner Construction Co., placed plank horses across the opening in the ice and hung the pipe from these in a vertical curve corresponding to the profile of the river bottom. When they had been jointed, they were carefully lowered, without changing the curve, until they were in place. Two flexible joints were inserted in the line, but the contractor found them a hindrance rather than an aid, because of the necessity for preparing special holes in the river bed to receive them.

About 430 ft. of 36-in. cast-iron main were laid as a single length at Milwaukee, Wis., in the winter of 1912–13. The river at the crossing has a maximum depth of 12 ft., and the trench in it was 4 ft. deep at the middle, gradually increasing to a maximum depth of 12 ft. near the shore. The pipe was laid from a trestle. Piles were driven 10 ft. apart transverse to the trench and 13 ft. apart along its length. After they were in place the trench was excavated with an orange-peel bucket operated from a scow. Timber cross-pieces were placed across the trench between the piles just above the water level, and on them the pipe were put together and jointed. The pile bents had heavy caps which were pierced by vertical holes through which long threaded iron rods 1-1/2 in. in diameter were passed. They had a hook at the lower end, from which the pipe was slung, and at the upper end there was a heavy nut which bore on a 6 × 6-in. iron plate placed on top of the cap. A man was stationed at each of these nuts with a wrench and at a given signal they gave the nuts a half turn. The rods were painted every 6 in. so that after the line was submerged there would be no question about its sinking into the trench in a fairly horizontal manner. After the pipe lay on the bottom a diver blocked it up at the low points, using timber wedges to make everything fast. The ends were connected with the shore mains in the usual way by the use of cofferdams.

A more difficult pipe-laying undertaking carried out in the same general manner was executed in connection with the outfall sewer of Honolulu. This pipe was a riveted steel main 24 in. in diameter, constructed on shore in 54-ft. sections. Each section was encased in a 4-in. shell of concrete before it was laid. In order to carry on operations across the hard coral reef, where the depth of water varied from 5 to 40 ft., a pile trestle carrying a 26-in. gage track was built on each side of the line of the outfall, the distance between the centers of the two trestles being about 15 ft. On these trestles a traveler was operated to carry the sections from the shore to the place where they were laid; each section was carried in four slings. The total length of the outfall constructed in this way was about 1700 ft.

This method was employed by Loring N. Farnum, as contractor, in 1904, in laying a 20-in. water main across the Kennebec River at Waterville, Me., for the Kennebec Water District, under the supervision of one of the authors. At the crossing the river is 800 ft. wide and averages 8 ft. in depth during the summer and autumn. For four-fifths of the distance the river bed is coarse gravel and the remainder is shale. Two rows of piles 18 ft. apart were first driven across the river, the piles in each row being 10 ft. apart. A brace pile was driven on the downstream side of every fourth or fifth pile in the downstream row. Each row was capped longitudinally with pairs of 6 × 10-in. stringers 30 ft. long bolted together through the top of each pile, which was cut to form a tenon 6 in. thick. On, and parallel to these caps were laid 8 × 12-in. stringers 30 ft. long, placed so as to break joints with the caps. The stringers served as a track on which was rolled a platform carrying a dredging outfit comprising boiler, hoisting engine and orange-peel excavator. With this outfit a trench 3 to 5 ft. deep was dug. The pipe-laying followed the dredging closely. To secure some flexibility in the pipe line every fourth joint was of the R. D. Wood Company, Ward flexible type, three ordinary lead joints intervening. A number of lengths were jointed above water and suspended from round logs laid across the timber track. As pipe was added at the outer end, that previously jointed was gradually lowered by slacking the ropes used for suspending the pipes. The limit of deflection at the flexible joint was 10 degrees, and although care was exercised to prevent reaching or exceeding this limit the bells of two flexible joints were cracked in the process of lowering, which shows the necessity of exercising great care in laying such pipe lines. The resident engineer on the work estimated the total cost, including overhead charges, to the contractor at $4.12 per foot, made up of $2.22 for the trestle and cofferdam, 47 cents for rock excavation, 6 cents for hauling pipe, 71 cents for laying pipe and 66 cents for dredging.

Where there is an unusual range to the tide, it is preferable at times to lay the pipe from scows rather than from trestles. For instance, in laying a submerged pipe line 30 in. in diameter and 2000 ft. long, forming an inverted siphon on the outfall sewer at New Rochelle, N. Y., a pair of 25 × 60-ft. scows was moored along the line of the trench in which the pipe were to be laid. This trench had previously been dug by means of a small dipper dredge and what rock had to be removed was drilled with drills mounted on wooden blocks which slid between vertical guides on the scows. The opening between the scows was directly over the trench. The pipe were jointed up in four lengths on planks laid from the deck of one scow to the deck of the other. When the joints were completed these pipe were raised by tackle hung from a frame over the center of each length, the planking previously supporting them was removed, and they were lowered to the bottom of the trench where the submerged joints were made by a diver. If the material near the trench had been washed into it enough to interfere with the pipe laying, the diver blew it out with a hydraulic jet, and if the trench was too low it was easy to raise the pipe by means of wedges and blocks.

The method of laying a 30-in. cast-iron outfall sewer at Salem, as described by W. F. Bates in *Eng. News*, May 28, 1908, differs somewhat from that generally employed where the pipe are lowered from scows. The contractor used a steam lighter and a tug; seven lengths of pipe were put together on the deck of the lighter and the joints run and calked in order to form a section for laying. A 15-in. I-beam about 75 ft. long, trussed laterally to prevent bending, was suspended from a block on the derrick boom of the lighter by four strands of wire rope, as shown in Fig. 113. To this beam the section of pipe was strapped with 1/2-in. wire rope, two straps to each length except the end lengths, which were held by a single strap. These straps were connected at one end by shackles with pins so placed that they could be easily removed by the diver and the straps released after the pipe was in position. This I-beam was used during the entire work and proved a satisfactory method of handling the section. The beam with a full section of 84 ft. of pipe weighed about 15 tons, and was easily handled by the derrick.

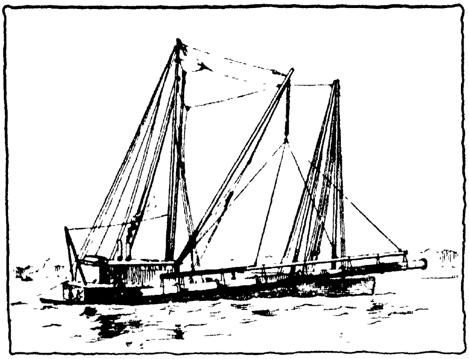


FIG. 113.—Lowering section of submerged outfall, Salem, Mass.

In this case, the pipe, after being lowered into the trench, which was from 12 to 18 in. below grade to give the diver plenty of room for working, was blocked up to the required grade and held in position by wedges. Guides were placed on the bell end of the pipe in position; these guides projected about 6 in. beyond the end and were made so as to help guide the spigot into the joint, and at the same time protect the lead from being jammed. The jointing of the special joint was directed by the diver. The lighter was placed and the guy on the derrick boom raised so that when the pipe was in position, by slacking the guy rope, the whole weight was brought to bear and pushed the spigot home without difficulty. The joint made under water was prepared on shore, by turning down in a lathe an ordinary spigot end to a slight taper. This spigot was inserted into a bell, the joint run full of lead, and the pipe then disconnected, leaving the lead in the bell; these pipes were connected again under water and calked by the diver.

One of the two lines of 60-in. cast-iron pipe forming the outfall sewer, 3288 ft. long, of the intercepting system at New Bedford, Mass., for which the authors were consulting engineers, was laid in 1913 in much the same way. The contractor, Patrick McGovern, first dredged the trench, most of which was in sand, gravel and clay, with some rock requiring blasting. The trench had an average depth of 8 ft., and the price for it was 55 cents per cubic yard, irrespective of material encountered. The pipe were assembled on shore in 48-ft. sections, each weighing about 30 tons and having a special taper joint at each end made up on shore, as described in the notes on the Salem outfall sewer. The section was suspended by wire ropes from a steel beam, which in turn was suspended from the boom of a derrick scow, thus enabling the section to be towed out from the shore and lowered into place without serious danger of injuring the joints. The contract price for this work, including backfilling the trench, was $16 per linear foot. The work was done under William F. Williams, at that time city engineer.

Where streams must be crossed in deep trenches and little is known regarding the character of the bottom, it is usually considered preferable to drive sheet piling and excavate under its protection, rather than to allow the trench to be dug with its banks at the natural slope of the material. For example, in laying a 48-in. gas main across the Harlem River at New York, in 1910, a 14-ft. trench was dug with the help of Lackawanna steel sheet piling. The channel here is about 550 ft. wide, and only half of it could be closed at once, since the river is used by many vessels. The trench had to be carried down at places more than 40 ft. below the surface of the water, and the river itself had a maximum depth of about 15 ft. at high water. The permit for laying the pipe received from the government required it to be 20 ft. below the bed of the river. As soon as the sheet piling was driven, the sand and gravel within the piling enclosure were removed by two centrifugal pumps mounted on a scow. A diver tended the suction of each pump and kept the material stirred up by means of a 3-in. water jet. When the material had been excavated to the full depth the bottom was covered with concrete and the pipe laid on it, the joints being made under water with lead wool and pneumatic tools. Two lengths of pipe were laid at a time, the joint between them being made up on the scow which lowered the lengths into place. This method of construction was also used about the same time for laying a line of 36-in. submerged pipe.

In each case the pipe has been covered with a longitudinal cap or coping of concrete, to prevent injury of the main by the spuds of dredges, anchors of vessels or the future deepening of the channel.

Floating Pipe.—Oil barrels have been utilized many times in submerged pipe laying. The most common method is to join a number of them together in two rows, each row covered with plank and supporting cross beams or cross trestles from which the pipe to be lowered are slung while being jointed, and then lowered into a trench previously excavated in the bottom of the stream.

An experienced layer of submerged pipe lines, A. L. Holmes, in a paper before the Central States Water Works Association in 1902, made the following statement regarding large pipe:

> In laying 24, 30 and 36-in. pipe in deep water the writer has connected 40 ft. with lead joints in the usual manner, placing on each end of this section a half of a bolted ball joint and lowering this into the trench prepared for it, holding one end off the bottom with a piece of wood 8 × 8 in. placed under the hub as the pipe was lowered into place. The next section prepared in the same way was lowered into place, and while in the slings and held just clear of the bottom the diver entered the ball into the bell and bolted it up, and so the process was continued.
>
> The pipe could all be put in shape to lower to the bottom in a harbor or where the work could be done most economically, and it was often the case that 500 ft. of large pipe were laid in this manner daily, which means that the work could be done cheaply and well. Bulkheads were placed over the ends of the pipe before they were placed in the water, to exclude fish and rubbish while lowering, and were removed by the diver and sent up for use again.

Mr. Holmes did not advise an attempt to get pipe very closely in line. If it zigzags a little it may become tighter when it settles, in his opinion. In fact, he recommends in river crossings a curve upstream, so that as the material washes out under the pipe and it works downstream, it may become tighter, if anything, at the joints.

Two 60-in. cast-iron pipe outfall sewers form part of the South Metropolitan Sewerage System of Boston and vicinity. These were laid in 1902-1903 in dredged trenches. The pipe were 12-ft. bell and spigot lengths, 1-1/2 in. thick and weighed 6 tons per length. The bottom of the pipe has an average depth of about 9 ft. below the bed of the harbor, and the trench was dredged 2 ft. deeper, to a maximum of 53 ft. below mean high water. The bottom of the trench was 10 ft. wide and the sides sloped so as to give a mean top width of about 30 ft. Dredging was in stiff clay.

In this trench 10-ft. piles were driven in 5-ft. bents of two piles each at intervals of 6 ft. These were capped by spruce timbers set to the required grade, thus ensuring two points of support for each pipe. The piles were driven with the assistance of a vertical telescopic guide box, 35 ft. long when closed, resting upon the bed of the harbor and capable of adjustment to varying depths of trench and conditions of tide. In this contrivance, a cylindrical hammer 10 ft. long descended upon a pile placed within the inner box. A 75-ft. lighter was used for the pile driving work.

The pipe were laid in 48-ft. sections, consisting of three lengths of ordinary spigot and socket pipe and one length having the spigot turned to a slight taper for a distance of 5-1/2 in. This spigot was readily inserted upon the wharf into the bell of the pipe which was to form the leading end of a section, and the vacant space entirely filled with lead, but without calking. The spigot was then withdrawn, to be used as the rear end of the following section.

The four pipes forming a section were then arranged, in their proper order, on a floating caisson lashed to the side of a second lighter, the three ordinary joints being run and calked in the usual manner. The caisson was a heavy timber structure of a special design patented by the contractor, 6 ft. square outside and 52 ft. long, built of 6-in. hard pine and divided by eight transverse bulkheads into nine compartments which could be separately flooded. On one face of the caisson eight timber saddles, shaped to the external contour of the pipe, served as a resting place for the pipe section, which was firmly secured by chains and turnbuckles. When filled with water the caisson was sufficiently heavy to sink, but when empty its flotation was sufficient to support a section weighing about 24 tons. On being released from the lighter, the section immediately turned over, so that the pipe were suspended from it in the water. Then, through openings controlled by plugs, the compartments were sufficiently flooded to sink the whole. Arrived at the bottom, still attached to the caisson, the pipe were adjusted by divers to line and grade, upon the caps, and the tapered spigot was drawn home in the leaded bell of the preceding section, by means of ratchet jacks actuated by levers. For the latter purpose the leaded bell was temporarily fitted with a collar provided with four guides to ensure the entry of the tapered spigot without damage to the lead mold. When the pipe were finally secured in position by wedges spiked to the pile caps, the caisson was filled with water, thus rendering it too heavy to float, and released from the completed section. It was then hauled to the surface by steam winches on the lighters and the water was forced out of the compartment by an air pump. The special joint between the sections was calked before the excavated material was deposited from the scows in the trench and over the pipe.

A riveted steel pipe, 5-1/4 ft. in diameter and about 2650 ft. long, is used as an outfall sewer into Lake Erie, at the end of the main intercepter of Cleveland. The pipe was delivered in 50-ft. lengths, with a heavy angle iron flange riveted on each end. These lengths were assembled into sections of 150 ft. on the dock, bulkheads were placed on the ends of these sections, and they were then towed about 8 miles to the trench excavated in the bottom of the lake to receive them. Openings were then made in the bulkheads, and the pipe were allowed to fill slowly and settle gradually into their place in the trench, where a diver connected the sections together by means of the special submarine joint shown in Fig. 114 (*Eng. News*, March 28, 1912).

The lightness of large steel pipe is sometimes an objection to their use, owing to the possibility that unless they are firmly bedded when landed on the bottom of the river or pond in which they are laid, the waves may roll them about. In order to avoid anything of this sort in the case of a 3-ft. steel pipe 600 ft. long, put together as a single length and then floated into position at Blackpool, England, transverse steel bed plates were riveted to the pipe at 18-ft. centers, in order to act as feet. This particular pipe was floated 3 miles from the place where it was put together on the shore, to its final position as an extension of an old outfall sewer.

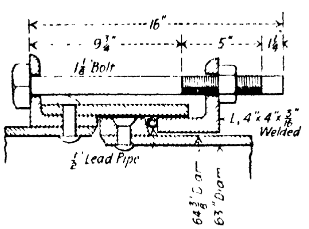


FIG. 114.—Submerged joint, Cleveland outfall

Where submerged outfalls extend a considerable distance from the shore, in localities exposed to heavy winds, it is frequently desirable to provide against these winds in drawing up the plans for construction. For instance, at Pensacola, Fla., where the sewage is discharged through a 24-in. outfall, 3000 ft. long, and a 20-in. outfall 2700 ft. long, the contractor originally provided two lines of piles along the trench in which each pipe was laid. These lines were intended to act as anchors for the pipe, which was put together on shore, with the free end bulk-headed, and then hauled out slowly, floating out into the bay between the lines of piles. The contractor feared that the pipe line would not float and attached a number of barrels to it. These became entangled with the piles, and eventually the contractor took up a large number of the piles. After this was done a heavy storm arose and the pipe line, having no piles to hold it on the leeward side, floated away, and a number of the joints were so strained that they leaked badly, allowing the pipe to settle to the bottom.

Pulling Pipe into Place.—An instance of the method of laying submerged pipe by hauling them out from the shore, was afforded by two lines of 18-in. pipe with flexible joints, each line about 500 ft. in length, constructed in 1910 at Vancouver. A chute was first constructed on one shore of the narrows to be crossed. This was built of 3 × 12-in. lumber supported by trestles, and was as long as the main to be submerged. The inner portion of the chute was greased like the ways of a shipyard and a short board was placed under the bell end of each pipe as it was laid in the trough. This pipe was furnished in 9-ft. lengths, and each flexible joint was capable of a deflection of 19 deg. After the entire line of pipe had been made up in this way, a 1-1/2-in. steel cable was drawn through it and fastened at each end to eye bolts of 2-in. Norway iron about 8 ft. long. These bolts passed through cast-iron caps at each end of the pipe. The rear bolt was threaded for about 6 ft. and was drawn taut by means of a large nut; the front bolt served to take up the strain from the rear bolt, through the cable, thus holding the lengths of pipe together and preventing much strain coming on the flexible joints. The pipe line was moved by three 1-1/2-in. steel hauling cables which were fastened to the pipe, one at the forward eye bolt, one at the front end and one a third of the distance back from the front end. The hauling cables were carried across the narrows and up a bank on the other side to five capstans, operated by horses and transmitting a strain of about 180 tons to the hauling cables. In order to prevent water entering the pipe and thus making the moving more difficult, air under a pressure of 50 to 60 lb. to the square inch was delivered continuously through the pipe while it was being moved.

It is not often that lengths of submerged pipe are entirely constructed on the shore before they are hauled across, as was the case at Vancouver. As a rule a few lengths are coupled together at the end of the section already in the water. This section is buoyed by oil barrels or other substantial floats, so that it does not drag along the bottom and offer resistance in this way to being hauled across the channel. For example, when E. L. Abbott laid a 10-in. main across the Missouri River at South Bend, Mo., he built a cradle of two 12 × 12-in. timbers, placed 9 in. apart in the clear and held together at the bottom by 2 × 10-in. timbers. This was built on the bank of the river extending out to deep water, and was long enough to lay and joint four lengths of pipe. Three empty barrels were attached to each length of pipe with ropes about 1 ft. shorter than the average depth of water. The end of the pipe in the river was plugged to keep out the water and had a rope attached to it, which was carried across the river and made fast to the drum of a hoist on the other shore. When a convenient number of lengths of pipe had been prepared on the cradle, they were pulled out into the stream by means of the hoist until all but the last length were under water. Additional lengths were than added to the shore end and the operation was repeated until the crossing was completed. Barrels floated all the pipe except the portion resting on the timber cradle, where the friction was slight, and the entire line was easily moved.

CHAPTER XII

JOINTING SEWER PIPE

Many of the early tile drains built in England and Germany had the joints filled with clay. Baldwin Latham says, in his "Sanitary Engineering" published in 1878, "the material most commonly used for jointing pipes is clay, which is one of the worst materials that could be found for the purpose." With the advent, however, of separate systems of sewerage and particularly of treatment plants, the matter of leakage became important and precluded the use of such unreliable material for jointing.

Cement, either neat or mixed with sand, was early employed, and although by no means ideal for this purpose, its use has become very extensive. It is very difficult, particularly in wet trenches, to make cement joints reasonably tight, and the water, especially running water, must be kept down below the cement in the joints until the mortar has acquired a fairly hard set. Furthermore, the rigidity of the joint after it has set is such that if any settlement takes place the pipe is likely to break. Consequently it is only natural that many attempts have been made to overcome the defects of the ordinary cement joint, either by varying the form of joint, or by using other materials, such as asphalt, sulphur and sand, tar and various patented mixtures.

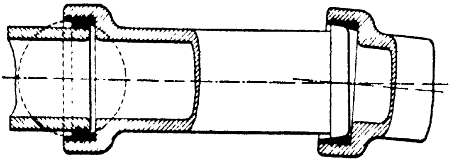


FIG 115 — The Stanford joint

The Stanford joint, Fig. 115, was much used in England at one time, and has been used at a few places in the United States. It is made by casting on the spigot and in the socket of each pipe, rings consisting of a mixture of sulphur, tar and sand. When the castings have hardened they are coated with oil or grease and the pipes shoved together, one ring fitting inside the other. This and similar types were developed by Doulton & Co., of London. Other forms have projections cast on one side of the spigot, so that when inserted in the socket this projection rests on the bottom and insures a correct centering of the pipe. Still other types have annular spaces cast on the inside of the socket, and after the spigot is inserted this space is filled with liquid cement poured through holes in the socket.

Pipe other than the simple bell and spigot type have never been much used in the United States, but various jointing materials have been employed to a considerable extent. A modification of the Stanford composition, consisting of heated sulphur and sand poured into the joint space in a way similar to that followed in making lead joints for cast-iron pipe, has given satisfaction in many places. Leadite, a patented article having a somewhat similar composition but mixed ready for use, gives similar results and seems to be more easily manipulated than the plain mixture of sulphur and sand. Another patented sulphur and sand composition is known as Pozite.

A preparation of a somewhat different type, known as G-K Compound, has been used at a number of places in the United States. It is melted at a high temperature and poured. When the joints are made with this or other similar material, they are somewhat flexible and are claimed to withstand slight settlement without fracture. It is claimed that it can be used successfully when the pipe are wet or partly under water.

Cement Joints.—The cement for joints may be used either neat or in proportions of 1 to 1 or 1 to 2 parts of sand, although the more cement there is in the mortar the more easily it will be molded and forced into place. When the cement is used neat there is a tendency toward shrinkage and cracks may develop. On the other hand, when mixed with sand it takes a somewhat longer time for it to set. It is usual before inserting the spigot of the pipe in the bell of the previous pipe, to place a gasket formed of a piece of jute or oakum, soaked in cement grout, around the spigot. The principal object of this gasket is to keep the pipe concentric and prevent the squeezing out of the mortar in the bottom of the joint. When no gasket is used, it is customary to place some mortar in the lower part of the bell before inserting the spigot of the next pipe. The function of this mortar is to hold the pipe in its proper position while making the joint, but in twisting and working the pipe into its proper position some of the mortar may be squeezed out and the joint may leak at this point.

After the pipe is in position, a man provided with a trowel and rubber gloves fills the joint carefully with mortar, working it into place with a wooden calking tool. The joint is usually overfilled, providing a bevel of about 45 deg., and the joint is well smoothed off. Tests have shown that these overfilled joints are customarily more nearly water-tight than flush joints. In some cases where unusual care is used, the joints are at first only partly filled with mortar and then another gasket is rammed into place flush with the outside of the bell, when the joint is overfilled with mortar. After the joint is made, it is well to wrap it with a piece of cheesecloth, securely tied at the top, thus holding the mortar in place, for there is a tendency for the mortar to sag and fall out of and away from the joint, especially if the mortar is rather wet. The use of cloth in this manner makes it possible to use a rather moist mortar with which a better joint can generally be made than with a dry stiff mortar.

The trenches in which the sewers of Batavia, N. Y., were laid in 1912 were unusually wet, and for this reason, although pumping was resorted to, no attempt was made to lay pipe in the dry. A patent gasket was employed for making the joints in the lower part of the pipe; this was a series of pockets of muslin cloth dipped in glue, the pockets between the partitions being filled with cement and sand mortar. One of these gaskets was placed in the invert of the bell of the last pipe laid. The pipe had deep and wide sockets; the spigot of the next pipe was entered into the bell of the preceding one at the top of the bell and then dropped. Its fall broke the partitions of glue in the gasket and made a ring of cement enclosed in muslin in the invert, which the pipe layer calked. The rest of the joint was made with oakum and cement in the ordinary way. This work was done under the direction of Charles Hoopes (*Eng. Record*, Nov. 19, 1912).

Pipe known as the deep and wide socket type have many advocates among engineers, but it is a matter of controversy as to how much advantage they have over the standard bell and spigot type. Tests made by Freeman C. Coffin and others indicate that deep and wide sockets are somewhat more likely to leak than standard sockets, owing to the large space which must be filled with more or less porous cement and sand. It is probable, on the whole, that the standard pipe will be found generally satisfactory, provided it is made as it should be, with the bells and spigots uniformly circular and of standard dimensions, so that there is everywhere the specified space for joints. Difficulties with standard pipe are largely due to the jointing space being so small in places that it is impossible to get the gasket and mortar into it properly.

One great trouble with poorly made cement joints is the entrance of roots of trees into the sewer. An almost capillary opening is all that is necessary to allow a root seeking moisture to obtain entrance, and after having gained an entrance it sometimes grows very rapidly, filling up the sewer and forcing the mortar out of the joints. When making a mortar joint in a wet trench it is, of course, desirable to keep water entirely away from the joint while it is being made, either by pumping or drainage in other ways. After the joint has been made earth may be carefully tamped under and around it, but unless the joint is provided with a band of cheesecloth tied around it to hold the mortar in place, there is always danger of knocking off the mortar or of its sagging away from the joint.

The amount of mortar required for making joints in pipe sewers may be estimated roughly with the aid of Table 56 compiled from Freeman C. Coffin's paper on "Tests of Cement Joints for Pipe Sewers" (*Jour. Assoc. Eng. Socs.*, 1894). These tables are for both flush and overfilled or beveled joints and for both standard and deep-and-wide sockets. Thicknesses of pipe shells and of cement spaces within bells differ, and consequently no table can be more than approximately correct.

TABLE 56.—CUBIC FEET OF MORTAR REQUIRED FOR 100 JOINTS IN PIPE SEWERS

(Freeman C. Coffin)

Diameter, inches	Joints finished flush		Overfilled joints	
	Standard	Deep socket	Standard	Deep socket
4	0.45	1.91	1.13	3.46
5	0.54	2.34	1.34	4.00
6	0.65	2.67	1.95	5.57
8	0.80	3.32	3.15	7.62
10	1.00	4.06	3.93	9.26
12	1.40	4.78	4.79	10.93
15	2.20	7.08	6.40	16.03
18	2.70	8.45	8.77	19.05
20	3.00	9.37	14.43	24.07
24	3.50	14.52	17.00	33.12

See Table 59 for quantity of materials for a cubic yard of mortar

Cement pipe sometimes have no bells. The joints are made with bands or rings, one end of each length having an inside bevel and the other an outside bevel, such as were used with some vitrified sewer pipe in England in the last quarter of the nineteenth century. Such pipe have been employed extensively in the vicinity of Los Angeles, Cal., and in *Eng. Rec.*, May 6, 1911, J. Alden Griffin, assistant engineer in the office of the city engineer of Los Angeles, published some suggestions regarding the jointing of such pipe. As with the usual bell-and-socket pipe, it was necessary to prepare the bed of the trench so that the pipe would rest securely along their entire length with the exception of the holes cut or dug under each pipe joint to receive the band. Special care had to be taken in adjusting the lengths of pipe to grade to prevent the workmen from doing this by using clods or other objects which would not give a permanently uniform stable support. In order to avoid repairing future leaks, it was found to be essential, when pipe have to be raised to produce a good grade, to throw dirt over the low portions of the trench and tamp it thoroughly. While this took time, digging up the pipe was a far more tedious operation.

It was early found that cement pipe could never be laid down hill and secure a satisfactory job, and that they must always be laid up hill so that the shrinkage of the joint could take place without cracking the band, the weight of the pipe being on the joint instead of pulling from it. In the climate of Los Angeles it has been found advisable never to place dirt on a new band in order to shade it, because the dirt absorbed moisture from the mortar and rendered it practically worthless. The new bands were best shaded from the direct rays of the sun for at least half an hour before placing any backfill on them, by means of canvas or boards laid across the trench. After the bands had set for half an hour it was found desirable to wet them and then add the backfilling. Great care was necessary in the backfilling or otherwise the joints would be cracked; the tendency of workmen to consolidate the filling by tramping on it had to be guarded against continually.

Where joints are made with cement mortar, particularly if gaskets are not used, there is danger of the mortar being forced into the interior of the pipe. If not removed, it will harden and form obstructions. It is therefore desirable to scrape clean the inner surface of the sewer as laid, for which purpose a "go-devil" has proved effective. It is made of two round wooden disks slightly smaller than the bore of the pipe. Each disk is made of two thin wooden blocks which are clamped together securely with a piece of cloth-insertion rubber packing between them, cut to fit tightly in the bore of the pipe. The disks are fastened together about 2 ft. apart by three 1/4-in. iron rods. A 3/4-in. Manila rope passing through and fastened to the disks is threaded through the pipe as laid, after which the go-devil is pulled along, effectually cleaning the pipe line. A poor substitute for this device is the swab or "half-moon," made from a piece of board cut to the curve of the interior of the pipe, but not filling it. This board, fastened to a stick a little longer than the pipe, is drawn along first on top and then on the bottom, to clean the completed sewer.

Tests of Cement Joints.—Tests of cement joints were made by Prof. Malverd A. Howe at the Rose Polytechnic Institute in 1892 (*Jour. Assn. Eng. Socs.*, June, 1891). They were made on the ordinary bell and spigot joint, the corrugated bell and spigot, ring joint, and the "Archer water-tight" joint made in England. The results of some of these tests are given in Volume I.

In 1894 Freeman C. Coffin carried out experiments on cement joints (*Jour. Assn. Eng. Socs.*, Dec., 1894), with Portland and Rosendale cement as jointing material, each of these being tried with and without the addition of sand. Tests were made under a uniform head of 5 ft. above the center of the pipe, which was considered the average head of ground water on sewers. The pipe used were 6 in. in diameter and in lengths of 1 ft. Three forms of joints were tested, the standard, the deep socket, and the deep socket with round-about grooves on the inside of the socket and outside of the spigot end of the pipe. Mr. Coffin expressed the opinion that with joints equally well made, the seepage would vary as the thickness of the joint and inversely as the depth, and in comparing the flush with the overfilled joints a decided gain from overfilling was found, although there was a greater eccentricity in the results of the overfilled joints.

In the tests of joints made with Rosendale cement it was found that the neat cement made a poorer record than either a 1:1 or 1:2 sand mixture. The best results seemed to be obtained when the mortar was of such consistency that the largest amount would stay upon a trowel, neither falling apart from dryness nor running from moisture.

Mr. Coffin summarizes his results as follows: With the standard joint the small amount of room for cement made it exceedingly difficult to make a full joint in the trench, and while the tests showed fairly good results he thought it impossible to approximate to such results in actual practice in a wet trench. For this reason he preferred to use a larger and deeper socket where tight work was desirable. With such sockets the mortar could be more easily put into the joint and a wooden rammer of sufficient thickness to be effective in compacting the mortar could be used. The greater depth of the joint appeared to reduce the seepage and to render it more likely that imperfectly filled portions of the joints would be covered by better compacted portions. It also gave a greater body of cement to resist the action of water reaching it before it set; and allowed the mortar to be placed within the joint instead of outside it. Mortar applied to the outside of joints was of doubtful value, he thought, in a trench where water was liable to reach it before it had set. The increased length of the joint aided very materially in preventing the pipe from moving in the joint and thus making a direct passage into it for the water. A gasket apparently increased the leakage by reducing the length of the joint and also the resistance to the passage of water; but in a very bad trench, where the water was likely to blow or wash the cement from the joint, it would prevent the sand from entering the pipe, and, if thoroughly saturated in a grout of neat cement, might aid in preventing the passage of water.

He advocated the use of 3-ft. instead of 2-ft. lengths of pipe, in order to reduce the number of joints, and also that two or more joints of the pipe should be put together on the bank and allowed to set before being placed in the trench. The difficulty in making joints on the bank was stated to lie in the alignment of the pipe. The ends were not square and true and could not be depended upon to give proper alignment.

F. A. Barbour, in connection with tests on the strength of sewer pipe, also made at Brockton, Mass., some tests of the joints (*Jour. Assn. Eng. Socs.*, Dec., 1897). He found the most notable result was the small leakage in shallow joints. He explained this result as follows: In the shallow joint the cement was perfectly hard and compact, following well the outline of the pipe, while in the deeper joint the clinging of the cement to the sides made it difficult to fill the space unless the width was proportionally increased, or efforts out of all comparison with actual practice were made. Experimentally a joint 3/4 in. deep was as watertight as one 3 in. deep made with the same effort. In practice the difficulty of keeping the green cement from falling out of a shallow joint made the allowable minimum depth of joint greater than this. The value of overfilling was very considerable. In tests of 1:1 and 1:2 mortar joints, the leakage differed but little from that with neat joints, and Mr. Barbour held that so long as the percentage of cement was sufficient to fill the voids in the sand, the leakage through mortar made of clean, sharp sand and cement should differ little from that through neat cement. He concluded that, experimentally, a tight joint, under a 5-ft. head, could be made by using dry mortar and sufficient tamping; that from joints made more nearly as in practice little information could be obtained; that all joints should be overfilled; that joints less than 1/2 in. wide could not be made tight without undue labor; that the difference between Rosendale and Portland cement joints was slight after an 18-hr. set; that an overfilled shallow joint was as tight as a deeper joint, unless great care, seldom taken in practice, was used to fill the deeper joint.

Sulphur and Sand Joints.—A composition of sulphur, tar and sand for joints has been used for a long time in England, in the preparation of the so-called Stanford joint, and is now used, without the tar, to a considerable extent in the United States. This jointing material consists of a mixture of about equal parts of very fine sand and sulphur, heated and poured like lead in making joints for cast-iron pipe.

There are some difficulties encountered in the manipulation of this material. The sand used should be very fine, and of such quality that no grit is felt when it is rubbed between the fingers. The mixture must not be made too hot, for if it is it changes from a liquid mass to a semi-plastic one that cannot be poured. It is, however, only necessary to cool it off to the proper temperature in order to make it become liquid again. For the manipulation of this material a gasoline furnace is very desirable, if not absolutely necessary, in order to be able to regulate the temperature properly. It is very desirable to build up a funnel or gate of clay, 3 in. or more in height, through which to fill the joint, as this pouring under a slight head or pressure fills the space better and takes better care of the shrinkage. The neck of the funnel should be at least 1/2 in. in diameter to prevent chilling of the liquid as it is poured.

With pipe up to 18 in. in diameter, it is customary to joint two or three lengths of pipe on the bank, which is a great advantage, as these joints can be made under the best possible conditions. In cold weather and with large pipe it is sometimes difficult to get the material to fill the bottom of the joint, as it cools very rapidly. A piece of jute thrown over the pipe close to the joint and lighted, will usually provide sufficient heat to prevent this difficulty. The use of sand in the mixture is to hold it to constant volume while cooling and to prevent shrinkage, which occurs if too little sand is used. It is very important to experiment in order to get the proper mixture, for it is found that with unsuitable or insufficient sand the shrinkage may be great enough to allow the sulphur to become loose from the pipes. If the sand is too coarse the mixture will not be uniform, for the sand sinks to the bottom of the heating kettle.

After the joints are poured they are sometimes painted or coated with a layer of roofing pitch to insure their water-tightness.

This type of joint has been used for many years at Newton, Mass., where it has given satisfaction. It is claimed that no cases have been found where roots of trees have obtained an entrance to sewers through such joints. It was also used as early as 1900, or thereabouts, for the sewers built by Alexander Potter for a number of municipalities in New Jersey. He employed a mixture of sulphur and sand in the proportions of 1 to 1, approximately, heated together at a temperature of 230° F. and poured in the usual manner. He reported that the physical and chemical tests of the mixture showed it to be superior in all respects to Portland cement mortar, both neat and mixed with sand, and his papers on the subject first called general attention to it in this country. Tests indicated that while the tensile strength of pure sulphur was about 100 lb. to the square inch, the sulphur and sand composition had a tensile strength of 400 to 700 lb. to the square inch. Several briquettes tested 2 hours after they had been poured broke at 670 lb. to the square inch. He had samples of the mixture analyzed, and found that under a 72-hour test the composition was not affected by any of the acids or alkaline liquors to which the samples were submitted when present in such quantities as are likely to be found in sewage. The tests also showed that the mixture was practically impervious to water, the absorption averaging 0.017 per cent.

The tests indicated that the more sand the sulphur could take up and yet run freely, the stronger the resultant mixture would be. They also showed that the finer the sand the more satisfactory the results. Coarse sand precipitated more rapidly and was practically useless. A sand which was satisfactory in use had an effective size of 0.135 mm. Experiments were made with fine Long Island beach sand, but this was found unsatisfactory.

This form of joint had the further advantage, Mr. Potter said, that water could be allowed to rise in the ditch 1 minute after the joint had been made. It was also proof against the intrusion of roots into the sewer. He found that under the conditions usually existing in sewer work, this joint would cost somewhat more than cement joints, but that if a reasonable effort was made to secure tight sewers with cement joints, the cost of joints of sulphur and sand would be no greater. The rigidity of joints formed of this material made it almost essential to deposit concrete under the haunches of the large pipe, he said. Tests were made with crude Sicilian, roll, and flour sulphur, the last being the most expensive of the three but the most satisfactory and easy to handle. The most serviceable size of melting pot was one holding enough material for at least three joints on the larger pipe and a dozen on the small pipe, at one time. The specific gravity of the melted mixture was 2.46, Mr. Potter said. The cost of the joints he gave in Table 57.

TABLE 57.—APPROXIMATE COST OF SULPHUR-SAND JOINTS

(Potter)

Diameter of pipe, inches	Mixture per joint, pounds	Cost per joint					Cost per foot for pipe lengths of	
		Mixture	Gasket	Fuel	Labor	Total	3 ft	2 ft
8	2.5	$0.031	$0.01	$0.01	$0.07	$0.121	$0.04	$0.06
10	3.3	0.041	0.01	0.01	0.08	0.141	0.045	0.07
12	4.2	0.052	0.01	0.01	0.09	0.162	0.055	0.08
15	5.5	0.069	0.01	0.01	0.10	0.187	0.065	0.095
18	7.0	0.087	0.02	0.02	0.11	0.247	0.08	0.12
20	8.0	0.10	0.02	0.02	0.12	0.260	0.09	0.13
22	9.0	0.1125	0.02	0.02	0.13	0.282	0.095	0.14
24	10.0	0.125	0.02	0.02	0.13	0.295	0.10	0.15

At Louisville (Report Sewerage Commission, 1907–1910) sulphur-sand joints were used in laying a large number of lateral sewers. In the preliminary stage of this work a mixture of sulphur and sand in equal parts was tried, a very fine molding sand from a local pit being used. From the first this mixture gave trouble, several radial cracks appearing on each joint as soon as the joint was poured, and about 12 hours after being poured the joint loosened, permitting the easy separation of pipe. Investigation showed that the sand contained a considerable percentage of clay. It was therefore washed, but the results were not much better. Finally another very fine sand with less clay in it was used, and that was found to work satisfactorily, particularly in a mixture of 6 parts molding sand, 4 parts Ohio River sand, and 10 parts sulphur. It was found that the mixture would practically melt at 200° F., and that it became thin and suitable for pouring at about 260° F. If the temperature rose more than 25° to 40° higher, however, the mixture would become thick and plastic and could not be poured.

After the joint had been poured, an asbestos jointer being used for the purpose, and while it was warm, it was coated with hot tar pitch as a further precaution against leakage. Within 5 minutes after the joint was poured, the entire length of three or four pipe, which had been put together on the bank, could be removed from the cradle and placed in position in the trench.

When water was encountered in the work, care was taken to hold its level below the pipe joints, as otherwise the liquid mixture did not enter the submerged portion of the joint. For joints formed on the bank it was found desirable to have a substantially built cradle with templets to hold the pipe accurately in alignment. It was found that good briquettes made of sulphur and sand of the proportions used on the works showed a tensile strength of from 520 to 640 lb. per square inch.

A difficulty with this kind of a joint is that it is absolutely rigid. As a result, unless the bottom of the trench conforms accurately to the shape of the pipe or if the backfilling is poorly done, the pipe are likely to become broken. This difficulty is not so great in the case of cement joints, although after the cement is set the joint is rigid. Much of the settlement and adjustment takes place before this occurs. Numerous attempts have been made to overcome this difficulty by the use of the so-called plastic joints, and many engineers look with considerable favor on the asphalt joint.

Asphalt and Tar Joints.—Asphalt joints have been used for many years in German cities, apparently with success, and in some places in the United States. An objection to the material is that it melts at a rather low point, which prevents its successful use in places where large quantities of hot water or steam find their way into the sewers, as is the case in some large cities. In Germany the engineers advocate the use of natural asphalt, but there is among American engineers a question as to the durability of this material, because of the possibility of its deterioration in the presence of water and chemical agents. Some coal-tar products may possibly be better adapted to this purpose, but there are no data of value on this subject.

Carl Henneking, City Engineer of Elberfeld, Germany (*Eng. Record*, Dec. 25, 1909), where asphalt has been used successfully for many years, gives the following necessary conditions for making satisfactory joints of this material:

1. The surfaces must be absolutely dry and clean before pouring.
2. The asphalt must be free from impurities which would tend to promote the formation of bubbles.
3. The asphalt must be very fluid.
4. The pour must be made at one time and continued until the asphalt reappears at the opposite side of the pour hole.
5. The pipes must be well aligned and the jute calked in so as to prevent the asphalt from entering the inside of the pipe.
6. The melting tank must be kept closed so as to prevent the escape of the light oils.

The average specific gravity of the asphalt used by Mr. Henneking was 1.32; it began to soften at 131° F., at 356° it became liquid, and at 378° it was ready to pour.

About 2000 ft. of 12-in. sewer were laid in 1908 at Monmouth, Ill., under the direction of John S. Bates, who used an asphalt joint on account of the very poor character of the cement joints made in the city just prior to that time. For the joint he used a preparation made by the American Asphaltum & Rubber Co., known as Pioneer Waterproofing Asphalt. In a description of the work in *Eng. Record*, Jan. 9, 1909, he stated that he used only enough oakum to prevent the melted asphalt from running through to the inside of the pipe. A jointer made of 1-in. square duck packing, smeared with mud to prevent the filler from sticking, was tamped firmly in place, care being taken that no water was left in the joint space to form steam. This was accomplished by enlarging the bell hole in the bottom of the trench and dipping this hole free of water just before placing the next pipe. The asphalt was heated in a kettle near the works and enough for a joint was easily handled and poured by one man. The time required for the complete joint was a little more than that necessary to make a cement joint. The filler required about 5 minutes to cool sufficiently to hold its shape and permit the gasket to be removed. The cooling was aided by pouring water from the bell hole over the joint. The work was much facilitated by making every alternate joint on the top of the bank, and thus reducing the amount of work to be done in the trench. In very shallow trenches, three lengths of pipe were joined on the bank, but this made too long a section to be handled easily as a rule. The joints made on the bank were made by standing a pipe vertically on the spigot end and placing a second pipe in position above it, so as to enable the two to be accurately centered before the oakum was inserted and the joint poured, this last work requiring no gasket.

Information relating to the cost of asphalt joints at North Attleborough, Mass., was given in *Eng. Record*, Nov. 18, 1911, by Frank A. Barbour, Consulting Engineer of the new sewerage system of that place. The sewers were in three sizes: 15 in. diameter, deep and wide socket pipe in 3-ft. lengths, 12-in. standard pipe in 3-ft. lengths, and 10-in. standard pipe in 3-ft. lengths. Two brands of asphaltic compound were used, the Pioneer Filler asphalt, furnished by the American Asphaltum & Rubber Co., at $28.50 f.o.b. Chicago per gross ton, and Kiola Asphalt Sewer Pipe Composition, furnished by Warren Brothers Co., at $28 f.o.b. Boston per gross ton. The former averaged 236 gal. per ton, making the weight per gallon 8.05 lb. and the price 12.1 cents per gallon. The latter was considerably heavier, running 145 gal. to the ton, so that the weight per gallon was 15 lb. and the price 19.3 cents per gallon. The joints were made by using three strands of jute gasket, which filled the joint to a depth of about 3/4 in., the remaining depth to the face of the bell being poured with hot asphalt, using a regular cast-iron pipe clip and overfilling with cement mortar on the outside.

For the 15-in. pipe sewer, from 3.37 to 5.7 lb. of asphalt were used per joint, and the cost was from 1.6 to 2.8 cents per foot of pipe. The cost of laying, including cement, was from 11.8 to 10.5 cents per foot.

On the 12-in. sewers 1.31 lb. of asphalt per joint were used, and the cost of laying, without cement, was 8.9 cents per foot. In laying the 10-in. pipe from 1 to 1.95 lb. of asphalt were used per joint and the cost of laying, without cement, was from 8.1 to 11.3 cents per foot.

E. J. Fort, Chief Eng. of Sewers, Brooklyn, N. Y., has recently drawn up a specification for bituminous joints which reads as follows:

> "All joints of the sanitary pipe sewers below the normal water table shall be made with a compound approved by the chief engineer. The compound shall preferably have a bituminous base, shall adhere firmly to the glazed surface of the pipe, shall melt and run freely at a temperature as low as 250° F., and when set shall be sufficiently elastic to permit of a slight movement of the pipe without injury to the joint or breaking the adhesion of the compound to the pipe. The compound shall not deteriorate when submerged in fresh or salt water or normal domestic sewage. It shall also show no deterioration of any kind when immersed for a period of 5 days in a 1 per cent. hydrochloric acid solution, nor when immersed for 5 days in a 5 per cent. solution of caustic potash. All sanitary pipe sewers shall be laid in a concrete cradle, as shown on the plans. The joints shall be carefully centered and calked in the usual manner. After the joint is properly calked, a suitable runner shall be placed and the compound, heated to a temperature of approximately 400° F., shall be poured from one side so that it shall run around the pipe and fill the annular space to a point 1/2 in. inside the outer rim of the bell of the pipe. After the joints are run and the concrete cradle placed, that part of the joint not imbedded in the concrete shall be further protected with a cement-mortar casing extending at least 3 in. from the face and outside of the bell. The cement-mortar shall be made of 1 part cement to 1 part of sand."

Tar-cement joints were used on a section of the East Jersey Joint Outlet Sewer, constructed under the direction of Alexander Potter for 11 different municipalities. This section was about 17,000 ft. long and consisted mainly of 22 and 24-in. vitrified pipe. About half of its length was laid in very wet trenches, and the liability of cement joints to permit infiltration of ground water in such a trench was the cause of the adoption of tar-cement joints. These were made by using strands of jute soaked in North Carolina tar as a gasket. This gasket was well calked into the annular space, the inside of the socket and the outside of the spigot of the pipe fitted together having been previously swabbed with tar.

Into a bucket full of Portland cement, North Carolina tar was poured and kneaded by hand with the cement until a material having the consistency of rather stiff dough was secured. This substance was then rolled on a board to a sufficient length and diameter, and placed in the annular space between the pipe to be jointed, where it was thoroughly rammed by a suitable tool and hammer until the space was filled to within 1/2 in. of the end of the socket. The usual beveled cement-mortar finish was then given the joint. In filling the annular space with this mixture Mr. Potter found that the weight of the material was often enough to cause the tar-cement to flow before it had set, causing it to drop away from the lower side of the upper portion of the bell. Moreover, unless the spigot of the pipe at the joint was supported on some solid bearing, such as a small chip or piece of vitrified clay, the weight of the pipe compressed the tar-cement in the bottom of the joint before it hardened, causing the filling material in the upper portion of the annular space to be drawn away from contact with the inside of the top of the bell, thus giving an opportunity for leakage in water-bearing ground. The tar-cement mixture when properly made becomes tough and hard in several hours, according to Mr. Potter, the time depending on the temperature and the proportion of cement incorporated into the mixture.

Tar-cement joints were later used extensively along the New Jersey coast in towns where water and quicksand are encountered. Much of this work has been done under the direction of Alexander Potter, who states that while there will be some leakage between the successive batches of the mixture inserted in the annular space of a pipe joint, the fact that this space is filled with a material which will stay there makes it, under such circumstances, preferable to cement. The material does not shrink and in small pipe the creeping which makes it objectionable in the larger sizes does not prove a drawback to its use. When reasonable restrictions as to water-tightness of sewers are demanded, Mr. Potter believes that this material can be used with economy. It is a slow process to employ, and is adapted to those difficult situations where the laying of a few pipe constitutes a fair day's work.

G-K Compound.—This product is described by the producers, the Union Clay Products Co., as "a homogeneous plastic mass composed largely of vulcanized linseed oil and a binder of anhydrous clay." It is furnished[1] in barrels of about 400 lb.; the stays are knocked away leaving the compound in a hard firm mass which is broken up with a hammer or hatchet when it is to be melted. In a sewer system constructed under the authors' direction, where the material was employed, it was heated by the contractor in a galvanized iron pail about 14 in. deep and 15 in. in diameter. This pail was used over a coke fire in an ordinary lead furnace, after a brief experience with a wood fire showing that the latter was unsatisfactory, because the flames would rise above the kettle and cause the compound to take fire, and at other times the temperature became altogether too low. The makers of the compound advise heating it on a gasoline furnace as being more easily regulated and more quick in melting the mass. While the compound is first heated, it bubbles and foams considerably, but after it has been melted for 15 to 30 min. the foaming subsides very largely and the compound is being "cooked," ready for pouring. The cooking must be repeated every time the compound is reheated. When in suitable condition for pouring it is as fluid as water, and the surface is apparently covered with a thin film of oil. It must be kept stirred constantly, for otherwise air bubbles will be found in the joint. If it is overheated it carbonizes and becomes entirely unfit for use. Experience shows that just before pouring the material should be stirred vigorously for a few minutes.

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[1] A. Elliott Kimberly informs the authors that on three sewerage systems with which he was connected, the bids for G-K joints averaged 21, 29 and 34 per cent. more than those for cement joints.

The inside of the bell and outside of the spigot end of the pipe at a joint should be wiped with a piece of cloth or jute before pouring the compound. Then the joint is calked with jute in order to prevent the melted compound from running into the pipe. This is quite important because as much as a handful of the compound has sometimes been taken from a joint, after the pouring, which indicates the amount of leakage that may occur through the jute into the interior of the pipe. An asbestos gasket, resembling a piece of canvas-covered lawn hose, except that it is not hollow, is used in pouring the joint. It is clamped at the top, leaving an opening through which the compound is poured into the joint space. This opening should be slightly off center, according to the Union Clay Products Co., so that the material as it flows in will drive out any water before it.[1] The pouring should be done immediately after the joint is calked so that the water will have no time to swell the jute. On the sewerage work done under the direction of the authors, already mentioned, a number of joints were poured with the water half-way to the crown of the pipe, without resulting in any imperfection in the joint which could be discovered on careful inspection. They do not, however, advise this practice under ordinary conditions. Apparently there is little difference in the behavior of the compound in hot and cold weather. The manufacturers state that about 0.6 lb. of the material is required for the joint in a 6-in. pipe and the amount increases up to 0.9 lb. per joint for 10-in. pipe. Experience on this work indicates that these figures are very low, although it is possible, of course, that with greater experience the contractor would have employed less material to obtain equally satisfactory joints.

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[1] A. Elliott Kimberly informed the authors that he had much trouble in following these directions in jointing standard 6-in pipe in 2-ft lengths. His assistant engineer, F. D. Stewart, reported that with the small annular space between the bell and spigot of such pipe, the compound hardened before it could flow entirely around the pipe, even though it was in a state of apparently maximum fluidity only 15 seconds before pouring. The temperature of the air was about 70° F. Mr. Stewart stated that he tried forming the pouring hole directly over the center of the pipe, so that the melted compound flowed down both sides at the same time. These joints were not entirely satisfactory, owing to their having unfilled spaces in the inverts of the pipes ranging in width from ⅛ to ¾ in. In these cases the joints were filled completely by pouring melted compound through a cardboard mold banked up with earth on the bottom and sides. While this method completely filled the jointing space, it was exceedingly wasteful of material.

The work was done with one man to attend to the heating and to pour half of the joints, those made on the bank, and to carry the melted compound to the pipe layer in the trench; two men to carry the jointed pipe with the help of a joist and lower it into the trench, and to assist from time to time on other work as they had the opportunity to do so; two pipe-layers to pour joints and lay pipe in the trench. In making joints on the bank, the pipe is placed with the bell end up and carefully plumbed, the spigot end of a second section is inserted in this bell, and the joint calked with jute and filled with the compound. In carrying on work on the bank, experience indicates that it is well to insist upon all pipe being carefully plumbed. Observation of the joints poured in this way indicates that there is some shrinkage of the compound as it cools, but it should be added that other engineers have reported that no shrinkage could be discovered.

A test of a 6-in. sewer of standard 2-ft. pipe with G-K joints was carried out by A. Elliott Kimberly, who states that although the hydrostatic pressure employed was only 5 lb. per square inch considerable leakage was apparent. On this line half of the joints were made on the bank and half in the ditch; the leakage occurred in both classes. Mr. Kimberly's experience and the information he has gathered from contractors have led him to draw up the following general rules for using this material for joints:

"1. Break up the material into comparatively small pieces before heating.

"2. Use a covered kettle to minimize volatilization of the oil.

"3. Use wood as fuel and heat rapidly. Preferably there should be designed a special furnace arranged to prevent the bare flames from coming in contact with the bottom of the melting pot.

"4. Do not attempt to draw off material from the kettle through the pipe unless the valve is jacketed, that is, is inside the kettle, especially during cold weather. Otherwise solidification of the compound will ensue.

"5. Do not prepare more melted compound than can be used for pouring one set of joints, vertical and ditch joints combined, in view of the fact that upon prolonged heating the material carbonizes in possibly a half hour after ebullition has ceased. Carbonization may be avoided, however, if fresh material is added as soon as all joints are poured that are ready for pouring.

"6. Do not attempt to use again material that remains in the kettle after a day's work is over.

"7. Invariably use deep and wide socket pipe, preferably in 3-ft. lengths."

Mr. Kimberly is strongly of the opinion that more calking material is required for poured joints of this type than for cement joints. There is a general opinion among those who have used the compound that more of it is required for joints than is indicated by the figures given by the makers, and the explanation of this discrepancy which Mr. Kimberley advances is that an unnecessarily large amount of jointing material and a small amount of jute are ordinarily employed now, although in view of his experience with leaky joints made with this compound it would hardly seem advisable to make any reduction in the quantity of the material upon which the impermeability of the joints depends until the subject has received further investigation.

Another jointing compound of the same general type is Marbleoid composed of linseed oil, sulphur and marble dust. Still other plastic jointing compounds are Jointite and Filtite, the latter being made in several grades for poured joints and also in a grade which is so stiff that it must be molded and pressed into the joints, a property claimed to be of value in making joints under water.

Tests of Pipe after Laying.—It is not customary in the United States to specify any particular tests for water-tightness after the sewer is laid, reliance being placed entirely on inspection during the progress of the work. In England and Germany, however, it is quite customary to specify hydrostatic or pneumatic tests of sections of the work before backfilling is allowed. The Manchester specifications for sewer construction say:

"The whole of the sewers and drains must be made thoroughly watertight and stand the following hydraulic test, appliances for which shall be supplied by the contractor, both before and after the earth is filled in to the satisfaction of the manager. The lower end of the drain will be closed by a properly fitted drain plug and the drain filled with water to a head of 4 ft. Any leaking or defective joints must be made good by and at the expense of the contractor."

Details of carrying out such tests are as follows: A plug is inserted in the lower end of the section under examination and at the upper end a right-angle bend facing upward, and two lengths of pipe are inserted. The sewer is then filled with water up to the top of the temporary upright pipes at the upper end. The rate of lowering the water in the upright pipe is noted, and from this it is possible to compute the leakage per foot of sewer for any stated period of time.

The amount of leakage allowed by different engineers varies greatly. Watson ("Sewerage Systems," p. 233) says that "in regard to 9-in. sewers, a test is regarded as satisfactory if the pipes do not leak at a rate exceeding 1100 (imp.) gallons per mile per 24 hours." It may be noted, however, that to lay sewers in such a way that the leakage would not exceed this amount requires exceedingly careful as well as expensive work. At Elberfeld, Germany (*Eng. Record*, Dec. 25, 1909), before putting the sewers into service, the ends are closed with iron plates fitted with rubber packing rings. Air pressure is then applied with a bicycle pump; if the pressure remains constant at 3.7 lb. for 19 minutes, the pipe is passed.

CHAPTER XIII

CONSTRUCTION OF BRICK AND BLOCK SEWERS

Usually vitrified pipe is the most practicable material for the construction of sewers less than 24 in. in diameter, and sometimes of much larger sewers. Among materials which may be used for the construction of large sewers are wood, stone, brick, concrete, reinforced concrete, iron and steel, and blocks of vitrified clay or concrete. Local conditions have an important bearing on the selection of materials for the construction of large sewers. In some places brick may be economically used, because they can be purchased at low prices and an ample supply of mason labor is available at reasonable prices, whereas their use in other places may be prohibitively expensive. Where stone may be had at very low prices, it may be wise to use it, although care should be taken to produce a smooth inner surface. In Paris many sewers have been built of rough quarry stone, laid in mortar and rendered inside with cement mortar, thus producing a smooth surface. Many of the oldest sewers in this country were constructed of wood and were either square or round. Some of these, while by no means satisfactory, have served their purpose for many years. As a temporary expedient, the use of wood may even now be justified under rare conditions. Cast-iron and steel pipe of large sizes have been and are now used under certain conditions, as for example, for the construction of inverted siphons and for sewer outlets.

While wood, iron and steel may be used for the construction of large sewers, in special cases, some kind of masonry must constitute the main reliance of the sewer builder. It is, therefore, important to determine which kind is most economical, and the decision must be based upon serviceability and durability, as well as upon cost. Where the serviceability and durability afforded by two or more materials are substantially equal, and the work is to be done by contract, it may be advisable to take bids upon the use of the several materials, finally selecting that which proves the least expensive. Where materials are thus thrown into competition, it is important to place all on an equal footing, that the comparison of prices may be fair. For example, if it is considered that brick is rougher than concrete, and therefore has less carrying capacity, but is otherwise equally desirable, allowance for this difference should be made in the sizes. In such cases the cost of extra excavation, as well as of extra masonry, must be taken into consideration.

Where tests are to be applied, they should be so specified that they will require of one material no qualities which are not possessed by the others, which perhaps may not be subject to the test. Reliance should not be placed upon a test to exclude some material, which, for reasons not covered by the test, is not considered suitable for the work in hand. It is also important to specify with exactness the character of materials to be used and the quality of workmanship required in the construction of sewers of different materials, that the bidders may be able to estimate with accuracy the cost of building the structure, and that these costs may be compared with fairness to those bidding upon different materials.

Quality of Workmanship.—When it is considered that sewers are built for at least a generation, and perhaps for hundreds of years, it is evident that consideration should be given to the character of workmanship employed. It is idle to provide specifications for elaborate tests of brick, cement and reinforcing steel, and to disregard the quality of workmanship which may have even a greater bearing upon the life and usefulness of the structure than the quality of the material entering into its construction.

Where it is necessary to exclude ground water from the sewers, so far as possible, they are logically designed to provide capacity for so much ground water as is unavoidably admitted to them. How absurd it is, then, to allow them to be constructed carelessly, with poorly filled joints or porous concrete which will permit leakage far in excess of that provided for in the original calculations. As the roughness of the inner surface has a bearing upon the carrying capacity and upon the formation of deposits, it is important to provide smooth inner surfaces.

As a rule it is practically as easy and it involves substantially no more expense to lay brickwork and place concrete in a workmanlike manner than in a careless and slovenly manner. It does, to be sure, require some knowledge of the art and some skill on the part of the masons and the concrete foremen, but these qualifications may be reasonably expected of those undertaking the work.

For the construction of concrete sewers the forms must be well made, water-tight, smooth and of accurate dimensions. Such forms may cost a few cents more per foot of sewer to be built than rough, ill-shaped and leaky forms, but the difference is practically negligible. It is equally important upon concrete work that the foreman knows the proper consistency for the concrete and that he sees that it is so handled that its components are not segregated and that it is sufficiently spaded. By giving attention to these points and exercising the proper care of his forms, it will be found as easy and no more expensive to do high-grade than poor work.

Pipe and Masonry Sewers, When Used.—Vitrified pipe is commonly used for sewers under 24 in. in diameter and may be had as large as 36 or 42 in. in diameter. Concrete pipe is more or less commonly used for sewers 36 to 48 in. in diameter and standard forms for pipe as large as 84 in. are on the market. For the construction of sewers too large to be economically and safely built of pipe, it is necessary to employ masonry. By far the largest proportion of such sewers have been built of brick or concrete, either plain or reinforced. The great advantage of monolithic concrete over most other materials used for masonry sewers lies in the fact that the thickness of the barrel may be varied according to requirements for strength. Such variations may be afforded to a limited extent by brickwork but not economically and conveniently as by concrete. Concrete has the further advantage that it can be readily reinforced with steel as required to meet the conditions encountered.

Where pipe is equally satisfactory in other respects, the decision as to where to change from pipe to masonry depends upon the relative cost. Monolithic unreinforced concrete has been used in successful competition with vitrified pipe of 24-in. diameter. It is not safe, however, to assume that either brick or concrete will be less expensive than pipe, but on the contrary, after acquiring a knowledge of the local conditions, careful comparative estimates should be made, or competitive bids should be obtained, to enable the engineer to make an intelligent decision between the two classes of material.

Cement pipe was used for many years in New England but it has been supplanted by vitrified clay pipe, which experience proved to be more durable and uniform in quality, although somewhat more expensive. It has been used extensively in the Borough of Brooklyn in recent years under rigid specifications and inspection; the method of manufacturing it in that borough is described in Volume I, page 352. West of the Mississippi a large amount of cement pipe is used in sewerage work. Much complaint about its quality has arisen, but specifications for it are now more complete and tests to determine the character of the product are more frequently made, so that an improvement in quality has doubtless occurred. As is evident from a consideration of the method of its manufacture, described in Volume I, page 350, such pipe must be carefully and intelligently made in order to be dense, hard and uniform, and it lacks the vitrified interior which is a leading advantageous feature of clay pipe. At present (1914) the general opinion is that vitrified pipe is better than cement pipe, but price considerations may render the latter advisable.

BRICK SEWERS

Quality of Sewer Brick.—Engineers have so long specified a certain grade of brick for use in sewer construction that the term "Sewer Brick" has come to be recognized by the trade as meaning hard-burned brick of good quality. Formerly when the kilns were made by hand and the fire was built directly in an opening in the pile of brick, there were marked differences in the quality of brick from different parts of the kiln, those in the outer part being under-burned and consequently soft, of poor quality and light colored. Those directly over the fire, known as "arch brick," were over-burned, often ill shaped, extremely hard and brittle, while those between these two extremes were of the best quality. With the more modern permanent kilns in use, the differences are not so great. The best of the brick should be selected, or specified, for the inner ring, and upon small work it is usually best to accept but one quality. They should be hard, regular in form and uniform in size. Upon large work it may be permissible to use some of the over-burned and slightly irregular brick for backing, if such a course will result in a material saving in cost.

The sizes of brick vary considerably in different places, and even those made by the same manufacturer differ somewhat according to the extent of burning, the hard-burned bricks being somewhat smaller than others. In 1899 the National Brickmakers Association established 2-1/4 X 4 X 8-1/4 in. as the standard size for common brick, although this size has not been adopted universally.

The importance of the size of the brick is not always fully realized. Usually there are brick of several sizes, from which those to be used may be selected. The harder brick being smaller, it is necessary to balance the advantages of the hard-burned smaller brick with those of the somewhat softer but larger brick. The decision should not be based wholly upon size, as the durability of the sewer is a matter of great importance.

A brick which is 8 in. long will gain in laying the equivalent of nearly 7 per cent. over the brick which is 7-1/2 in. in length. Similarly, the brick which is 2-1/4 in. thick will gain in laying about 12 per cent. over those which are 2 in. thick. Therefore, a saving of approximately 20 per per cent. in the cost of the brick may be effected by the use of those 2-1/4 in. thick by 8 in. long, instead of those 2 in. thick by 7-1/2 in. long. In addition to this, there will be a saving due to less mortar and labor required for laying the smaller number of brick, although the labor probably cannot be reduced in proportion to the reduction in the number of brick required.

Another consideration, although one which is more difficult to reduce to comparative figures, is the effect of the width of the brick. Many sewer brick are not more than 3-1/2 in. in width, although some will run 4 in. or more in width. The thickness of wall of a two-ring sewer built of 3-1/2-in. brick will be 7-1/2 in., excluding plaster, whereas the corresponding thickness of barrel built of 4-in. brick would be 8-1/2 in., an increase of over 14 per cent. If the two brick are of identical quality, a more massive structure will be secured with the use of the larger brick, with corresponding advantages.

While brick masonry is often computed in terms of cubic yards, it is customary in designing and considering different types of sewers to consider them as being made up of a certain number of rings of brickwork, rather than of the exact thickness of masonry to be obtained. It is therefore wise, when specifying that payments be made per cubic yard, to specify that the masonry shall be assumed to be of the required thickness and that computations will be based upon this assumption, even though the brick used may provide a thickness of sewer barrel slightly more or less than that stipulated.

The usual tests for determining the quality of brick are to determine the uniformity of size, texture, and absorption.

It is usually specified that brick from one place of manufacture shall not vary more than about 1/16 in. in thickness, nor more than 1/8 in. in width and length, and that the edges shall be uniformly straight and parallel. The texture should be fine and compact, and the brick should contain no fissures, air bubbles or pebbles, and when struck should give a clear ringing sound. The water absorbed by brick within a stated period, usually 24 hours, is an indication of the density and the extent of burning. Soft-burned brick from the outside of the kiln may absorb 30 to 35 per cent. by volume of water in 24 hours, while the overburned partially vitrified arch brick may absorb only 2 or 3 per cent. The limiting amount of absorption usually specified is between 10 and 20 per cent. by volume in 24 hours, equivalent to about one-half these quantities if calculated on the weight of the brick. The specifications of the New York Board of Water Supply state that the brick may be rejected if the absorption is over 16 per cent. Those of the City of Cincinnati specify not over 12 nor less than 2 per cent. by weight in 24 hours, for brick broken across the middle. Many specifications indicate no stated tests, but have a general requirement that the brick shall be of fine, compact texture and uniform size. The Metropolitan Sewerage Commission of Massachusetts has brick on exhibition of a quality similar to that required when purchases are made.

Tests for Sewer Brick.—For the determination of the quality of brick for sewer work, such simple tests as listening to the clearness of the ring when the brick are struck, estimating the relative weights of different brick by lifting them, and observing the color, shape and size, are usually relied upon. A compact brick of uniform texture, without fissures and air bubbles, will give a clear, ringing sound when struck. Pale color in brick from localities where the clay burns red, which is generally the case, signifies underburning. On the other hand, very dark colored brick are often overburned and partly vitrified. Brick shrink on burning, the hard dense brick being somewhat smaller than underburned brick from the same mold.

Specifications relating to uniformity of size and shape have already been mentioned. There is, however, one laboratory test sometimes required, namely, the determination of the percentage of absorption of water by the brick within a specified time. The results of such a test may be reported as a percentage by weights or by volumes. In the latter case the percentage is an indication of the porosity and may, depending on the specific gravity of the brick, be two or more times as much as the absorption by weight. This test is an indication of the efficiency of the burning of the brick, for soft underburned brick are porous and absorb a large amount of water, while hard burned vitrified brick will absorb little.

At Worcester, Mass., the absorption test is made as follows: The brick are first dried by placing them in an oven at 100° to 125° F. for a sufficient time to dry them completely. A test of the thoroughness of the drying may be made by weighing the brick and replacing them in the oven for an hour, after which they may be reweighed to determine if there is any further loss. After complete drying, the brick are weighed and placed in a small brass tank filled with water and provided with a gage glass which has a scale fixed at one side. The reading on the scale is taken and after 24 hours another reading of the scale is taken to show the volume of water absorbed. The brick are taken from the tank, the water on the outside removed with blotting paper, and the brick reweighed as a check on the direct volume determination.

Handling Brick.—A gang of five men will unload through a chute to wagons, a car of 12M brick in about 4 hours. When the brick are delivered on the job, they should be immediately culled by the contractor and rejected brick removed from the vicinity of the work, so as to prevent their accidental incorporation therein. It is sometimes allowable to use a certain number of bats or half brick in manholes; it is said that some engineers have required that brick for manholes be broken in two before laying, in order that the inner and outer surfaces of the masonry may conform more accurately to the true circular form. This practice is not considered good by some engineers, including the authors. Unless immediately required in the work, brick delivered upon streets subject to traffic, should be neatly piled in suitable locations that they may not obstruct traffic and at the same time may be within a reasonable distance from the work.

The method of passing the brick into the trench depends entirely upon local conditions, size of the work, depth of trench and congestion of working quarters. Brick are often lowered into the trench by hand, the load being made up of two parallel rows of brick 18 to 30 in. high., enclosed by the chain of a chain rope of suitable length. Such a rope is convenient for many uses about the trench. It is usually a 3/4-in. Manila rope provided with a hook at one end and a 1/4-in. twisted chain 7 ft. long at the other. In some cases, on large work where a derrick is available, the use of a skip may be desirable. The brick for a large Chicago sewer were wheeled to the side of the trench in wheelbarrows and delivered by tossing them, usually in pairs, from man to man located on a scaffolding.

Before placing brick in the work they should be thoroughly wetted, otherwise they will absorb water from the mortar before it has time to set. A sufficient number of tenders should be provided so that the masons may not be kept waiting, and the brick and mortar should always be so placed that the masons can conveniently reach them, as the less labor required of the mason the more brick he should lay.

Mortar.—Mortar for brick sewers is usually mixed by hand in mortar boxes placed on the side of the trench close to the work and is lowered to the masons in galvanized iron buckets, from a platform placed over the trench.

Many specifications contain the provision that sand shall be clean, sharp and coarse. The idea that sand for concrete should be sharp, that is, have angular grains, appears to have been due to several considerations, among which the following may be mentioned: Certain experiments have indicated that mortar formed with crushed stone screenings was stronger than when formed with natural sand. Also sand which contains considerable clay or organic matter or is extremely fine, all undesirable qualities, feels smooth as compared with a clean, coarse sand. Further there is less inclination when mortar is mixed very wet, for sand of sharp angular, and well-graded grains to sink to the bottom of the mass than is the case with smooth rounded grains of more or less uniform size. There is also some evidence that as originally used the word "sharpness" did not refer to the angularity of the grains but to the distinctively "sharp" sound given off when clean sand grains of quartz are rubbed together. As a matter of fact a given volume of sand with rounded grains contains less voids than the same volume of angular grains of similar character. Screenings, nevertheless, are often so graded as to form a more dense and consequently stronger mortar than some natural sands. In any case, whatever virtue sharp sand may have, meaning sand with angular grains, is completely obscured by the matter of voids and density, the proper sand to use being composed of such graded material, whether sharp or otherwise, as to give a mortar of greatest density. The requirement as to cleanness and freedom from loam and clay is important. Furthermore, it has come to be recognized as desirable to test the mortar made of the sand and cement it is proposed to use, as it is sometimes found that mortar made by mixing apparently good sand and cement lacks strength or soundness.

Brick Laying.—The brick should be laid by shoving or forcing them into a full bed of mortar, forming full joints on all sides, at one operation. In the United States brick are generally laid on the long and narrow side, with continuous longitudinal joints parallel to the axis of the sewer. This type of construction is known as the "rowlock" bond, the only bond between the inner and outer rings being that due to the adhesion of the cement in the joints. An interesting exception to the ordinary method of building sewer arches is that adopted at Cleveland in the construction of the Walworth Run Sewer (Volume I, p. 428), which has been described as follows:

> "For greater strength, the brick composing the arch were arranged in alternate headers and stretchers in Flemish bond, and, in order to avoid excessively thick mortar joints, as would be the case were the joints to continue radially from intrados to extrados, the masonry was broken up in cylindrical rings. . The entire arch was also cut into a certain number of segments separated by radial planes. The brick composing each segment included between these radial planes were laid up in rings, the inner and outer faces of which are parallel with the inner surface of the completed sewer. The radial distances between these parallel cylindrical surfaces are either 9, 13 or 17 in. The number of courses required to build one of these cylindrical rings for any particular segment is one more than the number contained in the next inner ring, and one less than the number contained in the next outer ring. By this means mortar joints of ordinary thickness are obtained in all portions of the arch, even to the extrados. The cylindrical surfaces separating the inner and outer rings of the segments are plastered smooth with Portland cement. The radial thickness of each cylindrical ring composing the superimposed segments of masonry is adjusted so as to break joint in adjoining segments by at least 4 in. Thus the completed arch consists of brick in Flemish masonry interlocked and bonded together by broken joints.
>
> "Apparently, this requirement would increase the cost of the masonry of the arch, but it was found by experience that as soon as the masons became familiar with the method of construction they placed in the wall nearly as many brick per day as in a straight wall laid in English bond." (Walter Camp Parmley, Trans. Am. Soc. C. E., vol. lv, p. 358.)

The longitudinal face joints should be made as narrow as practicable and usually will be from 1/4 to 3/8 in. in thickness. The joints between the rings should also be made thin, not exceeding 1/2 in. unless it is desired to put in a wide joint for the special purpose of preventing infiltration. The exterior of the arch is often covered with a plaster of cement mortar 1/2 in. in thickness. Centers used for the temporary support of the brickwork are often drawn as soon as the last of the key has been laid and the plastering completed. After the centers have been removed the interior surface of the sewer should be cleaned and pointed as smooth as possible. In some cases one or two coats of cement wash have been applied to the inner surface for the purpose of reducing roughness.

Where the trench is composed of suitable material, the bottom is trimmed to conform to the desired outside surface of the invert masonry, and each brick laid directly on a bed of mortar placed on the bottom. Templates, commonly called "profiles" in the eastern part of the country, built and set as described in Chapter XV, "Forms and Centers," are placed in position and a mason's line tightly drawn between them. Brick are then laid in a single row in the center of the bottom of the invert for the full length of the section, about 12 ft. The several rows of brick are then laid on either side, care being taken to lay each brick accurately to line at the time it is slid into place. A skillful mason will rarely touch the brick after the joint is made, and hammering a portion of the wall to bring it to line should be discouraged, as the adhesion of mortar to brick may be destroyed in this way. Care should be taken to see that the outside ring of brick is well supported by the bank. It frequently happens that the trench cannot be excavated exactly to the line of the proposed brickwork, in which case masons will often fill the space between the brickwork and the bank with loose material insufficiently rammed. In fact it is very difficult to ram the material filling this space without injuring the green masonry. It seems probable that many of the cracks which have been found in brick sewers may be attributed to loose and improper filling between masonry and the solid bank of the trench. Care should be taken in laying the arch rings to see that all joints are properly filled and not unnecessarily thick. The key should be laid by an experienced mason who realizes the importance of tight joints and a well-fitting key properly forced into place, that there may be no injury to nor failure of the arch when the centers are struck.

After the first few courses in the invert are laid, it is wise to provide a few loose boards or planks upon which the masons and tenders may walk, thus protecting the green brickwork from injury, due to movement of the brick resulting in a lack of adhesion of mortar to the surface of the brick. Upon large sewers the invert may become so high that it will be necessary to provide a working platform for masons and tenders. In building such platforms care should be taken to protect the green masonry from injury.

In trenches in wet or loose material when the soil will not maintain any given shape, the brickwork may be laid in a cradle. Such a cradle may be constructed of ribs cut to the shape of the outside of the invert, making an allowance for the thickness of the planks which are to form the cradle proper. These ribs are set in the bottom of the trench at the proper elevation and 2-in. planks are nailed to them, earth being carefully tamped behind each one as it is put in place. After the cradle is constructed, the process of laying the brick is similar to that mentioned above. Where the trench is in unstable material the sewer may be constructed upon a concrete foundation laid directly upon the soil or upon a wooden platform, this part of the sewer being constructed ahead of the brickwork. In other cases, where the soil has little bearing power, it may be necessary to construct the sewer on a pile platform as illustrated in Volume I.

The number of brick which a mason can lay in a given time depends to a considerable extent on the size of the sewer. This is because more time is required to lay the brick in the face or inner ring of the invert, where the brick should be laid accurately to line and the joints made as narrow as possible, than is needed for laying the brick in the other rings, which are relatively rough work. There is a similar although much less marked difference in the time required for laying the inner ring and the other rings of the arch. As the brick forming the arch are laid upon the centers, less time is required than where the brick are laid to line, as in the invert. Where the sewer is small, the working space is sometimes so restricted that the mason is unable to work to the best advantage. Upon such sewers the proportion of face work is much greater than upon large sewers. Some very small sewers have been built of a single ring of brickwork, in which 100 per cent. of the masonry is face work. As the size increases, so that two rings are required, the proportion of face work is reduced 50 per cent., with a decrease in the care required and difficulty involved in laying the brick.

In an investigation for the Boston Finance Commission (Report Boston Finance Commission, vol. iii, 1909), it was found that on the contract work of the Massachusetts Metropolitan Sewerage Commission, the number of brick laid per hour per mason varied from 384 on a sewer 13 ft. 6 in. by 11 ft. 3 in. to 165 per hour on a 36-in. circular section. There is, however, a great chance for loss of time in this class of work, unless it is well systematized. For instance, in the investigation mentioned, it was found that on certain large sewers built by day labor in the city of Boston, the number of brick laid per mason per hour averaged only about seventy. This appears to have been due largely to inability to keep the masons properly employed. It is extremely important that the construction be so conducted as to provide ample work at all times for the masons, otherwise the cost of the masonry will be greatly increased.

The number of brick per cubic foot of masonry and the amount of mortar, etc., required for circular and egg-shaped sewers are given in Fig. 116 (by Geo. S. Pierson, *Eng. News*, May 17, 1900) and Table 58. The amounts of cement and sand required per cubic yard of plastic mortar are given in Table 59 from "Concrete, Plain and Reinforced," by Taylor and Thompson. This table is based on average results of a large number of actual experiments, but at best can be considered only approximate, as so much depends on the quality of cement, character of the sand and the amount of water used.

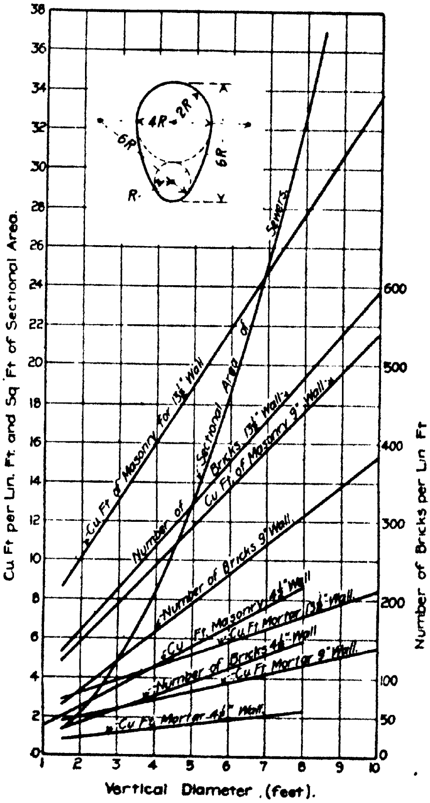


FIG. 116.—Quantities for egg-shaped sewers.

A considerable force is necessary for handling the materials for the masons. On a sewer at Denver, Colo. (Gillette's "Cost Data," p. 42), 6 to 8 ft. in diameter, 18 brick layers were employed in three gangs, the total force amounting to 80 men equivalent to about 3-1/2 tenders per mason. Parts of this sewer were composed of three rings of brickwork. In portions of the work where wet trench was encountered, the foundation and rough work of the invert were of concrete and stone masonry. The rough invert was lined with a single ring of brick and the arch was composed of three rings of brick.

TABLE 58.—NUMBER OF BRICK PER FOOT OF SEWER

Size of brick, 2 × 3-1/2 × 7-1/2 in.; Face joints, 3/8 in.; Ring joints and plaster, 1/2 in.

(George S. Pierson)

Diameter	Circular sewers			Egg-shaped sewers[1] (referred to vertical diameter)		
	1 ring	2 rings	3 rings	1 ring	2 rings	3 rings
2 ft. 0 in.	48.38			40.70		
2 ft. 3 in.	54.43			45.79		
2 ft. 6 in.	60.47			50.88		
2 ft. 9 in.	66.52			55.97		
3 ft. 0 in.	72.57	161.24		61.06	138.23	
3 ft. 3 in.	78.61	173.34		66.15	148.41	
3 ft. 6 in.	84.66	185.43		71.24	158.58	
3 ft. 9 in.	90.70	197.52		76.33	168.76	
4 ft. 0 in.	96.75	209.61		81.41	178.93	
4 ft. 3 in.		221.70			189.11	
4 ft. 6 in.		233.80			199.29	
4 ft. 9 in.		245.89			209.46	
5 ft. 0 in.		257.99	411.19		219.64	353.65
5 ft. 3 in.		270.08	429.33		229.81	368.91
5 ft. 6 in.		282.18	447.47		239.99	384.18
5 ft. 9 in.		294.27	465.61		250.17	399.44
6 ft. 0 in.		306.37	483.75		260.34	414.70
6 ft. 3 in.		318.46	501.89		270.52	429.96
6 ft. 6 in.		330.56	520.03		280.69	445.23
6 ft. 9 in.		342.65	538.17		290.87	460.49
7 ft. 0 in.		354.75	556.31		301.05	475.75
7 ft. 3 in.		366.84	574.46		311.22	491.02
7 ft. 6 in.		378.94	592.60		321.40	506.28
7 ft. 9 in.		391.03	610.74		331.57	521.54
8 ft. 0 in.		403.13	628.88		341.75	536.81
8 ft. 3 in.		415.22	647.02		351.93	552.07
8 ft. 6 in.		427.32	665.16		362.10	567.33
8 ft. 9 in.		439.41	683.30		372.28	582.59
9 ft. 0 in.		451.51	701.45		382.45	597.86

[1] Proportions as shown on Fig. 116.

The number of men per mason depends, of course, largely on the working conditions. If they are such that material can be delivered close to the trench, at the points required, the number of men may be reduced considerably. The size and character of the brickwork also

TABLE 59.—VOLUME OF PLASTIC MORTAR AND QUANTITIES OF MATERIALS PER CUBIC YARD

(Reprinted by permission from "Concrete, Plain and Reinforced," second edition, Taylor & Thompson)

Relative proportions by volume[1]		Cubic feet of compacted plastic mortar						Materials for 1 cu yd compact plastic mortar based on barrel of					
		From 1 cu ft cement			From 1 bbl cement			3.5 cu ft		3.8 cu. ft[2]		4 cu ft	
		Based on Portland cement weighing			Based on barrel containing								
Cement	Sand	108 lb per cu ft	100 lb per cu ft	95 lb per cu ft	3.5 cu ft	3.8 cu ft	4 cu. ft	Packed cement	Loose sand	Packed cement	Loose sand	Packed cement	Loose sand
								bbl	cu yd	bbl	cu yd	bbl	cu. yd.
1	0	0.93	0.86	0.80	3.2	3.2	3.2	8.31		8.31	.	8.31	. . .
1	½	1.12	1.06	1.02	3.9	4.0	4.1	6.92	0.46	6.73	0.47	6.61	0.49
1	1	1.48	1.42	1.38	5.2	5.4	5.5	5.22	0.68	5.01	0.71	4.88	0.72
1	1½	1.84	1.78	1.74	6.4	6.7	7.0	4.20	0.81	4.00	0.84	3.87	0.86
1	2	2.20	2.14	2.11	7.7	8.1	8.4	3.51	0.91	3.32	0.93	3.21	0.95
1	2½	2.56	2.50	2.47	9.0	9.5	9.9	3.01	0.98	2.84	1.00	2.74	1.01
1	3	2.92	2.86	2.83	10.2	10.9	11.3	2.64	1.03	2.48	1.05	2.39	1.06
1	3½	3.28	3.23	3.19	11.5	12.2	12.8	2.35	1.06	2.20	1.08	2.12	1.10
1	4	3.64	3.59	3.55	12.8	13.6	14.2	2.12	1.10	1.98	1.11	1.90	1.13
1	4½	4.01	3.95	3.91	14.0	15.0	15.6	1.92	1.12	1.80	1.14	1.72	1.15
1	5	4.37	4.31	4.28	15.3	16.4	17.1	1.77	1.15	1.65	1.16	1.58	1.17
1	5½	4.73	4.67	4.64	16.6	17.7	18.5	1.63	1.16	1.52	1.18	1.46	1.19
1	6	5.09	5.03	5.00	17.8	19.1	20.0	1.52	1.18	1.41	1.19	1.35	1.20
1	6½	5.45	5.39	5.36	19.1	20.5	21.4	1.41	1.19	1.32	1.21	1.26	1.21
1	7	5.81	5.76	5.72	20.3	21.9	22.9	1.33	1.21	1.23	1.21	1.18	1.22
1	7½	6.18	6.13	6.08	21.6	23.2	24.3	1.25	1.21	1.16	1.22	1.11	1.23
1	8	6.54	6.48	6.44	22.9	24.6	25.8	1.18	1.22	1.10	1.24	1.05	1.24

[1] Cement as packed by manufacturer, sand loose

[2] Use these columns ordinarily.

Note.—Variations in the fineness of the sand and the cement, and in the consistency of the mortar may affect the values by 10 per cent. in either direction.

have a considerable influence. On small sewers, where the brick masons cannot work as rapidly or to as great advantage as on large work, the number of men required to keep them busy is smaller than in other cases. Even on small sewers, however, a force of from 2 to 3 men per mason, is required. At Cleveland (*Eng. Rec.*, April 8, 1905), on a sewer 12 to 13-1/2 ft. in diameter, 2 masons and 6 laborers were employed in laying a double-ring brick lining on the bottom.

Rate of Progress.—The rate of progress in the construction of brick sewers generally depends more largely upon the practicable rate of progress of excavation than upon that of constructing the masonry. Disregarding the progress of excavation, however, the rate of progress of masonry construction is limited in small sewers by the working space, and in large sewers by the economic problem of handling large quantities of materials, largely by hand within a limited space. For instance, on a 7-ft. sewer at Gary, Ind., about 60 ft. were built daily. This involved the employment of about 75 men for handling upward of 100 tons of material within a limited space. For smaller sewers, say 3 to 4 ft. in diameter, 3 masons are about all that can work to advantage on one section. A 4-ft. circular sewer built of two rings of brickwork, the brick being each 2 × 3-1/2 × 7-1/2 in., requires 209.61 brick per foot (see Table 58). If each of the masons lays on the average 2500 brick per day, 3 can build about 36 ft. of sewer per day.

Cost of Brick Sewers.—The cost of brick sewers depends on a number of local factors surrounding the work, such as accessibility and restricted working space as well as upon the length of day, prices of labor and materials and efficiency of the force. Given certain assumed figures the cost of brickwork may be estimated as follows:

Assuming that each mason will lay 2500 brick per day of 8 hours, that 3 laborers will be required per mason for mixing mortar, handling brick, and moving centers; that there are 500 brick per cubic yard of masonry; that the amount of 1:2 mortar required is 0.3 cu. yd. per cubic yard of masonry requiring approximately 1 bbl. of cement and 0.28 cu. yd. of sand; and that the day's work of 1 mason will amount to 5 cu. yd., the cost of this 5 cu. yd. will be as follows:

1 mason at $6.00	$6 00
3 laborers at $2.00	6 00
2500 brick at $9.00 per M	22 50
5 bbl. cement at $1.80	9 00
1.4 cu. yd. sand at $1.00	1 40
Centers at $0.05 per cu. yd	0 25
	$45 15
Supervision, lumber and tools, 15 per cent.	6 77
	$51.92

This is about $10.40 per cubic yard, or $20.80 per 1000 brick laid. If such work was done by contract, add 15 to 20 per cent. profit, making about $12 per cubic yard, equivalent to $24 per 1000 brick laid. The cost of brickwork in sewers is in general between $10 and $14 per cubic yard (equivalent to $20 to $28 per 1000 brick), and is greater in small than in large sewers.

VITRIFIED BLOCK SEWERS

A vitrified sewer block was put on the market in 1911 by the American Sewer Pipe Co. for use in the construction of sewers from 30 to 108 in. in diameter. Fig. 117 shows such a sewer under construction. The advantages claimed for it are that the material is salt glazed vitrified clay, and therefore the sewer will have a hard, smooth interior surface; the blocks are large, thus limiting the number of transverse and longitudinal joints; the blocks are quickly and easily laid and backfilling can follow immediately after the completion of the barrel of the sewer, thus making it possible to prosecute the work with a relatively short open trench. One of the objections to the blocks appears to be the difficulty of making water-tight end joints. If the blocks are so laid as to allow the bottom openings to serve as subdrains, which is claimed as one of the advantages of this type of construction, it is difficult to make a water-tight end joint, and unless special care is taken these joints will not be water-tight. Less difficulty attends the making of the longitudinal joints water-tight, because of the length of surface which is in contact with the mortar, and because of the dovetailed offset. The sides of the blocks are scratched, or corrugated, to assist in forming a tight joint.

Fig. 117.—Vitrified block sewer.

The blocks are made in three types, *A* for sewers 84 to 108 in. in diameter inclusive, *B* for sewers 48 to 78 in. and *C* for sewers 24 to 45 in. They are shown in Fig. 118 and in Table 60 the dimensions of types *B* and *C* are given. The end overhang of the outer part of the block over the inner part is 1-1/2 in. in all sizes. The price of the blocks in 1913 was $9 per ton net at the factory at Akron. Branch blocks are made to facilitate the connection of lateral and house sewers.

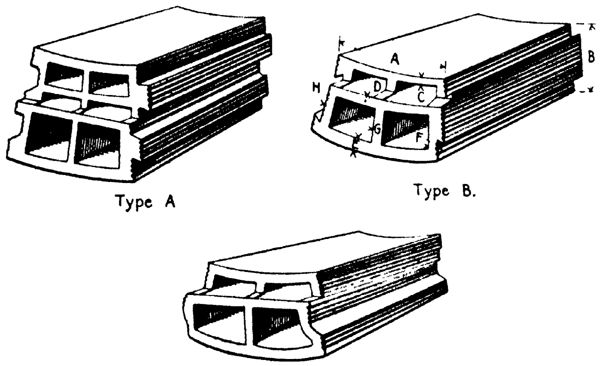
The blocks are laid to line and grade in the invert with the aid of templates like those used in building brick sewers. The arch blocks can be laid on centers like brick, but the American Sewer Pipe Co. leases a special center for this purpose. The planks forming the lagging are moved in and out by an eccentric motion when a handle is turned, the continuous longitudinal joints coming on the planks. Centers are supplied for each size of sewer. The transverse joints are broken.

TABLE 60.—DIMENSIONS OF VITRIFIED SEGMENT SEWER BLOCK
(American Sewer Pipe Co.)

Diameter of sewer, inches	Length of block, inches	Weight of block per foot, pounds	Blocks to circle, number	Dimensions in inches, Fig. 133							
				A	B	C	D	E	F	G	H
24	24	23	8	$9\frac{1}{16}$	4	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{5}{8}$
27	24	23	9	$9\frac{1}{16}$	4	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{5}{8}$
30[1]	24	[illegible]	10	$9\frac{1}{16}$	$4\frac{1}{2}$	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{11}{16}$
36	24	23	12	$9\frac{1}{16}$	$4\frac{1}{2}$	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{11}{16}$
39	24	27	12	$9\frac{1}{16}$	$5\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{3}{4}$
42	24	27	14	$9\frac{1}{16}$	$5\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{3}{4}$
48	24	36	14	$10\frac{1}{4}$	6	$\frac{27}{32}$	$\frac{23}{32}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{7}{8}$
54	24	37	16	$10\frac{5}{16}$	6	$\frac{27}{32}$	$\frac{23}{32}$	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{7}{8}$
60	24	47	16	$10\frac{3}{16}$	$7\frac{1}{4}$	$\frac{15}{16}$	$\frac{11}{16}$	1	1	$\frac{11}{16}$	1
72	24	$46\frac{1}{2}$	20	$10\frac{11}{16}$	$7\frac{7}{16}$	1	$\frac{13}{16}$	$1\frac{1}{16}$	1	$\frac{3}{4}$	1

[1] A 33-in. sewer requires 11 blocks.

Note.—The dimensions in this table are only approximate, as some of them were scaled from blue prints and all are subject to variation as the dies of the block machines become worn.



Type A

Type B.

FIG. 118.—Types of vitrified blocks for sewers

CONCRETE BLOCK SEWERS

Cast concrete blocks have been used to some extent in the construction of sewers. This method of construction has been developed largely through the efforts of Walter C. Parmley, who holds certain patents covering portions of his process of manufacture. Mr. Parmley states that his system of construction consists principally in placing the trans-

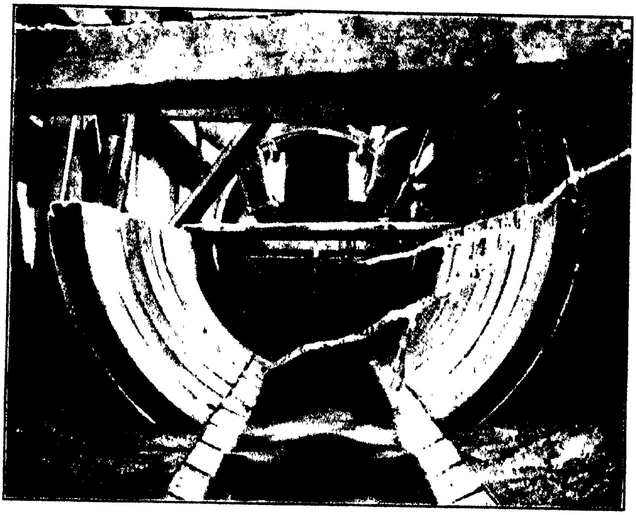


FIG 119 —Concrete block sewer under construction.

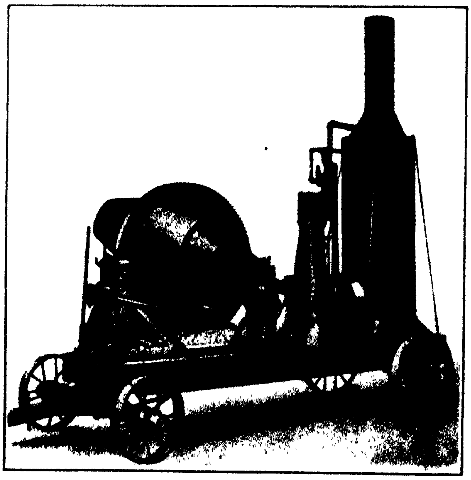


FIG 120 —A tilting mixer (Smith).

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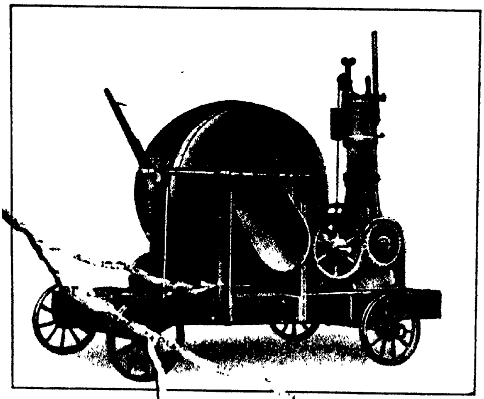


Fig. 121.—Mixer with discharging chute (Ransome).

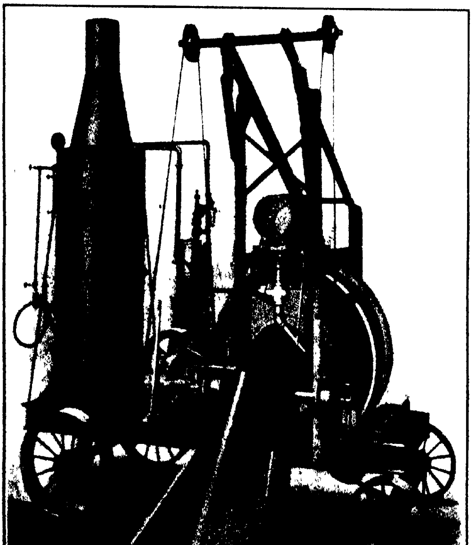


Fig. 122.—Mixer with charger (Koehring).

verse reinforcement so as to follow the regions of tension throughout the arch or ring, together with various other transverse and longitudinal bars so combined as to give effective reinforcement for both primary and secondary stresses. These various arrangements of bars are also combined with specially molded concrete blocks so as to make a structure, built up in place, of unit pieces or interlocking sections and embedding an effective steel reinforcement skeleton. The segmental block construction has been used for circular sewers from 18 to 120 in. in diameter and for egg-shaped sewers up to 56 × 84 in. in size.

Mr. Parmley claims the following advantages from the use of his system: 1. The most efficient placing of steel in which the tensional regions of the intrados are anchored against those of the extrados of the arch. 2. Efficient reinforcement with a minimum quantity of steel. 3. In construction with segmental blocks the highest quality of manufactured concrete, with resulting imperviousness. 4. Practicability of laying segments in water and allowing water to pass at once over inverts constructed of them. 5. Practicability of backfilling trenches immediately after completion of segmental block sewers. 6. Blocks can be laid without centering, or with only skeleton templates for support, the same to be immediately removed after the key block has been placed. 7. Segmental blocks can be easily placed in tunnels. Another advantage of block construction is the rapidity with which the sewer can be laid. There is no delay due to the difficulties in placing concrete or to the time required for the setting of concrete before the load can be applied or the forms removed.

The number of blocks required for a complete ring of sewer 12 in. in length varies with the size, from four to fourteen. The thickness of blocks, quantity of concrete, the quantity and size of steel, and the weight of each ring per linear foot, for the several sizes, are given in Table 61. The heaviest block used weighs 180 lb. and is required for the construction of a sewer 48 in. in diameter. The usual weight of block varies from 100 to 125 lb. The invert blocks are laid end to end without any special rabbet or other provision for jointing. After the blocks are laid, grout is poured into the joints until they are completely filled.

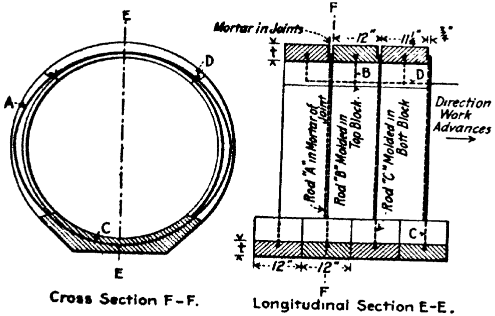
The concrete blocks are cast in cast-iron molds. The concrete may be made either wet or dry, according to the wishes of the engineer; it is more common at the present time to use a wet mixture containing all the water the concrete will hold without quaking. Fig. 119 shows a concrete block sewer under construction, the invert blocks alone being laid in the foreground, the side blocks are placed in the middle distance, and in the background the arch is in place on a special type of center used with these blocks. This form of construction is used for lining tunnels and building manholes, and can be employed where the upper part of the trench must be kept so narrow that at the bottom the banks must be undercut in order to place the side blocks in position.

TABLE 61.—CONCRETE BLOCK SEWER INFORMATION

(Parmley System)

Diameter, in.	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81	84	87
Segments, no.	4	4	4	4	4	4	4	4	4	6	6	6	6	10	10	10	10	14	14	14	14	14
Concrete:																						
Thickness, in.	2¼	2¼	2½	2½	3	3¼	3½	3¾	4	4	4	4	4	4	4½	4½	[illegible]	5	5½	5½	6	6
Cu. ft. per lin. ft.	1.52	1.70	2.07	2.26	2.68	3.14	3.63	4.23	4.80	4.90	5.17	5.44	5.71	5.90	6.95	7.2[illegible]	8.4	8.69	10.06	10.42	11.78	12.17
Steel:																						
Rod *A*, in.	3/16	3/16	⅜	⅜	⅜	⅜	⅜	⅜	⅜	7/16	7/16	7/16	7/16	½	½	[illegible]	9/16	9/16	9/16	⅝	⅝	⅝
Rod *B*, in.	3/16	3/16	⅜	⅜	⅜	⅜	⅜	⅜	⅜	7/16	7/16	7/16	7/16	⅜	⅜	⅜	⅜				.	.
Rod *C*, in.	3/16	3/16	⅜	⅜	⅜	⅜	⅜	⅜	⅜	7/16	7/16	7/16	7/16	⅜	⅜	⅜	⅜				.	.
Bar *D*, in.	¾ × 3/16	1 × 3/16	1 × 3/16	1 × 3/16	1 × 3/16	1 × 3/16	1 × 3/16	1 × 3/16	1 × 3/16	5/16	5/16	5/16	5/16	[illegible]	⅜	[illegible]	⅜	⅜	⅜	⅜	⅜	⅜
Lb. per lin. ft.	2.69	2.95	4.46	4.83	5.23	5.63	6.02	6.43	6.83	9.45	9.92	10.38	10.85	14.35	14.9[illegible]	18.54	19.35	17.03	17.63	19.73	22.43	23.13

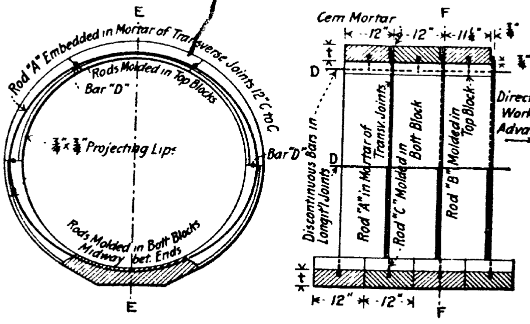
Note.—All blocks are 12 in. wide, those for the sides and arch having a ¾-in. rabbet along one side in which the *A* rods are placed and then covered with mortar, which makes the joint tight.



F
D
A
C
E
Mortar in Joints
12"
11¼"
¾"
t
B
D
Rod "A" in Mortar of Joint
Rod "B" Molded in Top Block
Rod "C" Molded in Bott Block
Direction Work Advances
C
12"
12"
F

Cross Section F-F. Longitudinal Section E-E.

Four-Segment Type.



E
Rod "A" Embedded in Mortar of Transverse Joints 12" C to C
Rods Molded in Top Blocks
Bar "D"
¾"x¾" Projecting Lips
Bar "D"
Rods Molded in Bott Blocks Midway bet. Ends
E
Cem Mortar
F
12"
12"
11¼"
¾"
t
D
Discontinuous Bars in Longit'l Joints
D
Rod "A" in Mortar of Transv. Joints
Rod "C" Molded in Bott Block
Rod "B" Molded in Top Block
Direction Work Advances
12"
12"
F

Cross Section F-F. Longitudinal Section E-E.

Six-Segment Type.

It is claimed that little labor is required for handling and placing the blocks. Upon the construction of a 72-in. sewer, in tunnel, in Toledo, Ohio, the masonry gang consisted of only three men, a mason, a helper and a man to bring the blocks and mortar from the foot of the shaft to the heading. From 20 to 25 lin. ft. of sewer were constructed by this gang in an 8-hour shift. The proprietor of this process will act either as manufacturer of the blocks delivering them to the contractor, or as patentee, conveying to the contractor the right to make the blocks for the work in hand.

CONSTRUCTION OF MANHOLES

Where 8-in work is used, the brick may be laid as headers with the long sides forming radial joints, or in common bond with several courses forming double rows of stretchers to be followed by a course of headers laid with the long sides making radial joints. In manholes requiring 12 in. of brickwork, the bond is complicated by the fact that if the joints are made radial the outer portion will become very wide. This may be obviated by laying the outer rings with ordinary 3/8-or 1/2-in. joints and introducing stretchers or headers, as the case may be, when the opportunity offers, filling in the gaps with broken or half brick.

A good mason can lay the brick by eye so as to conform with accuracy to the prescribed line. On small sewers the pipe are usually left out where manholes are to be built. A foundation of concrete or brick is first laid up to the invert of the sewer, which is then formed either with brick, concrete or a split tile of the same diameter as the sewer. The shapes of the floors differ somewhat, and illustrations of a number will be found in Volume I under Manholes.

Great care should be taken in the construction of manholes to have all joints in the brickwork well filled with mortar. A fruitful source of leakage is the joints around the pipes entering the manhole. These should be filled and where possible the hub of the pipe should be laid in the masonry, forming a cut-off.

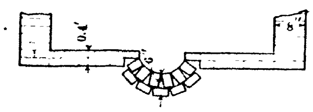
By the use of Table 62 the quantity of brickwork in a 3 × 4-ft. oval or 4-ft. circular manhole can be readily calculated. The cost of brick manholes may be analyzed in the same way as the cost of brick sewers. Many masons cannot lay as many brick in manholes as in large sewers, although an experienced rapid mason may accomplish nearly as much. There is no expense for providing and handling forms.

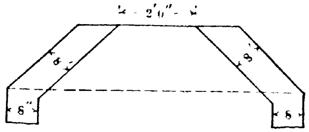
A manhole, having a depth of 10 ft. with a dome of 3 ft., would, according to Table 62, require about 2.26 + 0.83 + 0.35 = 3.44 cu. yd. of masonry. This will cost, at $10.40 per cu. yd., $35.80; the cover will cost $8., and 8 steps at 20 cents will be $1.60, making a total of $45.40. Brick manholes without covers will cost from $3.50 to $4 per foot to depths of 12 ft., and from $4 to $6 per foot for greater depths.

TABLE 62.—CUBIC YARDS OF BRICKWORK IN MANHOLES

Heights, ft.	Barrel				Dome		Floors		
	8-in. brickwork		12-in. brickwork		8-in brickwork				
	3 × 4 ft.	4 × 4 ft	3 × 4 ft.	4 × 4 ft.	3 × 4 ft	4 × 4 ft			
1.0	0.32	0 36	0 52	0 58					...
2.0*	0.65	0.72	1 05	1 16	0 58	0 65	4 ft. × 4 ft	Flush M.H. floor	0.33
3.0	0.97	1.09	1 57	1 75	0 83	0 91	3 ft. × 4 ft.	2-way 8-in. invert	0.32
4.0	1.29	1.45	2 09	2 33	1 09	1 18	3 ft. × 4 ft	2-way 10-in. invert	0.34
5.0	1.62	1.81	2 62	2 91	1 34	1 46	3 ft. × 4 ft	2-way 12-in. invert	0.35
6.0	1.94	2.17	3 14	3 49	1 61	1 74	3 ft × 4 ft	2-way 15-in. invert	0 37
7 0	2.26	2 53	3 67	4 07	1 87	2 01	3 ft × 4 ft	2-way 18-in. invert	0 39
8.0	2.59	2 90	4 19	4 65	2 13	2 30	3 ft. × 4 ft	2-way 20-in. invert	0 40
9.0	2 91	3 26	4 71	5 24	2 40	2 58			
10.0	3.23	3 62	5 24	5 82	2 66	2 86			
0.1	0 03	0 04	0 05	0 06	0 03	0 03	4 ft × 4 ft	3-way 8-in., invert	0 41
0.2	0 06	0 07	0 10	0 12	0 05	0 06	4 ft. × 4 ft	2-way 12-in., 1-way 8-in.	0 43
0.3	0.10	0.11	0 16	0 17	0 08	0 09	4 ft. × 4 ft	2-way 12-in., 2-way 8-in.	0 44
0.4	0.13	0.14	0 21	0 23	0 11	0 12	4 ft. × 4 ft.	2-way 15-in., 1-way 8-in.	0 44
0.5	0.16	0 18	0 26	0 29	0 13	0 15	4 ft. × 4 ft	2-way 18-in., 1-way 8-in.	0 46
0.6	0.19	0 22	0 31	0 35	0 16	0 17	4 ft. × 4 ft.	2-way 20-in., 1-way 8-in.	0 47
0.7	0.23	0 25	0 37	0 41	0 19	0.20			
0.8	0 26	0 29	0 42	0 47	0 21	0 23			
0.9	0.29	0 33	0 47	0 52	0 24	0 26			

Note.—Walls and dome figured 8 in. thick, floors 0.4 ft. and inverts 6 in. thick. Floors and inverts figured to outside of 8-in. sidewall, domes 2 ft. diameter at top.





CHAPTER XIV

CONSTRUCTION OF CONCRETE SEWERS

Until about 1900, large sewers were generally constructed of brick, although concrete was used to a limited extent, particularly in Washington, D. C. Since 1900, the use of brick masonry has gradually given way to that of concrete, until at the present time sewers are commonly built of concrete, although it is by no means the only material used. At first concrete and brick masonry were frequently combined; the concrete was used for the foundation of brick sewers or for reinforcing or backing up brick arches; inverts were built of concrete and the arches of brick, or inverts of brick and arches of concrete; or the structure in part or in whole was built of concrete and lined with brick. Recently extensive systems of large sewers have been built almost exclusively of concrete.

In a broad way the causes for this change are similar to those which have operated to increase the use of concrete for all construction work. Greater production has lessened the cost of Portland cement, while the rising cost of and difficulties with mason and other labor have also tended to increase the use of concrete. With this increased use, improved machinery and appliances for mixing and placing the concrete have been provided, which have proved a factor of considerable importance in building large sewers. Concrete possesses some advantages over brickwork under most conditions, and other advantages under special conditions. Likewise brickwork possesses certain advantages over concrete under many conditions and certain advantages under special conditions.

Some of the advantages possessed by concrete may be briefly discussed. With good workmanship it is generally possible to secure a smoother inner surface than with brickwork, although where the latter is used much can be accomplished in this direction by carefully pointing the joints and washing the inner surface with one or two coats of Portland cement grout. Some engineers feel that the increased carrying capacity of a well-built concrete sewer, due to smoothness, is enough greater than that of a brick sewer to warrant a slight reduction in size, thus tending to reduce the cost by the use of concrete.

Under many conditions a concrete sewer can be built at less cost per cubic yard of masonry than a brick sewer. Perhaps one of the most important advantages of concrete over brickwork is due to the fact that its thickness can be varied gradually so as to provide the necessary thickness of wall at all points, and prevent unnecessary thickness at any, thus greatly reducing the quantity of masonry required for the structure. That concrete can be readily reinforced with steel fabric or bars is also an important advantage. The fact that machinery and appliances can be had for mixing and placing concrete makes its use particularly advantageous upon large sewers, and the fact that little skilled labor is required makes its use advantageous upon both large and small sewers.

While concrete has not been used upon sewer construction for a sufficiently long time to warrant final conclusions as to its durability, the evidence at hand indicates that the life of well-made concrete will be equal to that of ordinary brickwork.

It has been maintained by some engineers that it is easier to construct a practically impervious sewer of brick than of concrete, because of the opportunities of breaking joints and of well filling the joints between the rings of brick. This opinion is not heard so frequently now that the use of concrete has become more general, and it is probable that with an equal amount of care the concrete sewer can be made at least equally impervious to infiltration. Distinct advantages in the use of brickwork lie in the facts that it can be built in short sections; that the centers and forms may be removed almost immediately after the brickwork has been placed; and that it is not necessary to keep long sections of the trench open for considerable periods of time, which is the case where the sewer is to be built of concrete. In restricted trenches where it is necessary to put in short sections from time to time, brickwork generally possesses a distinct advantage.

The decision between the use of concrete and of brick masonry depends largely upon local conditions, the character of workmanship which can be secured, the quality and cost of brick and other materials available, the price to be paid for masons and other labor, the size of the structure to be built, and the necessity of working in very short sections. All of these conditions and many other facts should be taken into consideration before deciding which material to use.

Inverts.—Upon relatively steep grades, and especially where sand and gravel are likely to find their way into the sewer, ordinary brickwork is subject to erosion. Concrete appears to be subject to about the same wear, but perhaps is not quite so easily repaired as the brick invert, a single course of which can be removed and relaid with comparative ease. The removal of a definite portion of the concrete invert is a matter of considerable difficulty. In some cases, however, brick inverts have been repaired with concrete instead of relaying the inner ring of brick.

For reasons stated in Volume I, under conditions of high velocity, say in excess of 8 ft. per second, and where the sewers carry a considerable amount of abrasive material, concrete and ordinary brick inverts must be expected to show considerable wear in the course of 15 to 30 years. Under such conditions vitrified brick may be used to advantage for lining the invert.

Disintegration of Concrete by Chemical Action.—At a number of places in Europe and America concrete as well as brick sewers have disintegrated, sometimes to an extent requiring reconstruction. Concrete, being of a calcarious nature, is affected by acids, some of which may be discharged from industrial establishments like wire drawing and pickling works, or they may be formed indirectly by the decomposition of sewage, during which process hydrogen sulphide may be generated and given off into the air in the sewer, where it comes in intimate contact with the concrete. While dry hydrogen sulphide gas does not appear to attack concrete, it is easily oxidized to sulphuric acid, which has a very deleterious action. Such action would be equally injurious to the mortar in the joints of brickwork, but brick masonry possesses some advantage over concrete in that these joints, if taken early, can be raked out and repointed, a process which is not readily applicable to a concrete arch, repairs to which must be more extensive and made at considerably greater cost.

At Los Angeles, Cal., an outfall sewer was built in 1895, portions consisting of wood-stave pipe, of brick and of brick and concrete. The line included two long inverted siphons and a tunnel. Soon after construction it was noticed that disintegration of the mortar of the brickwork was taking place. This action was most noticeable near the outlet of the inverted siphons and at another point where the sewage dropped some 12 ft., thus allowing the liberation of large quantities of gases.

Under normal conditions the sewage occupied many hours in traversing the inverted siphon and on emerging was in a septic condition. Investigations by Homer Hamlin, then Chief Deputy and later City Engineer (*Eng. News*, Nov. 8, 1900), indicated that the destructive agent was sulphuric acid created by the oxidation of hydrogen sulphide gas, formed by the putrefaction of organic matter in the sewage and liberated from it. The gases were absorbed by drops of condensation hanging from the arch, and the acid thus came in intimate contact with the masonry. Thus sulphuric acid attacked the cement, forming compounds which crystallized in the pores of the cement with great expansive force, causing disintegration similar to that due to freezing. Analyses of drops of water attached to the surface of the masonry showed them to be strongly acid. Some of the structures connected with this line had to be rebuilt and some years afterward the whole line was reconstructed in a new location, although disintegration of the masonry was only one of the factors which resulted in the new construction.

Similar effects have been noticed in some septic tanks constructed of concrete, the most severe action taking place near the flow line of the sewage.

At Great Falls, Mont., a sewer constructed of Portland concrete pipe showed so much deterioration after a short period of service as to necessitate reconstruction of certain portions (Trans. Am. Soc. C. E., vol. lxiii). It appears that here, instead of being due to any effect of sewage or gas, the disintegration was caused by strongly alkaline water surrounding the outside and percolating through the wall of the sewer. The action was similar to that noted in other places where water containing large quantities of sulphates is encountered, such as sea water or water from arid regions, and resulted in disintegration by the formation of compounds accompanied by expansion in the pores of the concrete.

This deterioration is by no means universal, even when conditions apparently similar to the above are encountered, and is less when the concrete is dense, thus preventing the entrance of chemically laden moisture into the body of the masonry. In fact, the best precautions which are apparent at the present time for preventing deterioration appear to be the use of dense mixtures, waterproofing compounds, or coatings which prevent water from penetrating beyond the surface of the concrete. Attempts have been made to attack the problem from a chemical standpoint, particularly in France, where some of the cement companies have been more or less successful in producing a "non-decomposable" cement. This has been largely done by reducing so far as possible the percentage of alumina in the cement, as it is to the alumina compounds formed by the chemical action of the sulphates in the water that the expansion and consequent disintegration appear to be largely due. The lime in the cement is also involved in the action and attempts have been made to neutralize its effects by mixing with the cement material which will combine with the free lime and form insoluble compounds.

This action is not confined to mortar and concrete alone but brick, underburned clay tile, and even stone have been attacked by alkaline waters. In the case of septic sewage accompanied by the evolution of hydrogen sulphide gas, the action seems to be more energetic when the water contains quantities of mineral sulphates, the production of hydrogen sulphide alone from organic compounds being insufficient to produce serious results in most cases.

It is probable that the injurious effect of gases upon concrete and mortar will be more evident in warm climates, because of the more vigorous decomposition going on in the sewage and the deposits from it. The following opinion of E. P. Richards, City Engineer's office, Madras, India, is pertinent:

> ". . . . . . I should like to add a warning on this danger. We have a number of small concrete pipe drains and sewers in Madras, mostly 6-in., 9-in., and 12-in. diameter. They have been laid some seven or eight years, and are now found in many places to be corroded very badly indeed. The disintegration in every case is internal, and in the soffit. In some pipes scarcely any thickness is left, and collapse is taking place. The sewage has a high temperature here, and decomposes rapidly; and these sewers have never been ventilated properly. The pipes themselves appear to be of quite good hard concrete, and the inverts are usually as good as new. We attribute the corrosion to sewer gas" (*Surveyor*, Apr. 5, 1912, p. 539).

Finally it may be stated that great quantities of concrete have been and are being used with satisfactory results, even in places where, according to the isolated cases noted, disintegration might be expected. The conditions likely to produce disintegration of the concrete or of the cement mortar in the brick joints are the presence of deleterious chemicals, porosity of the concrete or mortar, bad ventilation, strength and staleness of the sewage, frost action, and the presence of salt or alkaline water coupled with the conditions stated. No definite conclusions can be drawn, but in locations where disintegration is considered possible, concrete should be used with caution and steps should be taken to minimize any possible serious results.

Use of Materials Excavated from Trench.—In some localities much of the sand and gravel for constructing concrete sewers may be obtained from the trench itself. In a few cases the sand and gravel excavated have been of such quality and so graded that they were used without screening. It is quite unusual, however, to find the combination such that the requisite proportions of each can be obtained without an undue amount of screening. Sand generally predominates to such an extent that it is cheaper to transport the gravel from a distance rather than screen the large amount of material necessary to obtain it directly from the trench.

In the construction of the Bronx Valley sewer (*Eng. Rec.*, Oct. 22, 1910) part of the sand was obtained from the trench but required washing before use. This was accomplished in a box 14 ft. long, 14 in. wide and with a depth varying from zero to 4 ft. A weir was cut in one side near the top, for the discharge of dirty water and fine material. A 12-in. perforated pipe was laid on the sloping bottom for about half the length of the box, through which water flowed for agitating and washing the material.

When the trench is through rock it may be economical upon large work, where the demand for stone is great, to install a rock crusher and screens for manufacturing the concrete aggregate. In building a large sewer 3000 ft. long, in St. Louis (*Eng. News*, July 30, 1908), the contractors installed a No. 3 Gates crusher with a conveyor for elevating the stone to screens from which it dropped into bins. This plant was placed near a railroad siding where sand and cement were received and where the concrete mixer was located. Materials were conveyed to and from the work by means of an industrial railway.

This piece of work was a very large one, involving a great amount of materials to be delivered within a distance economically and practically reached from a permanent plant. Portable outfits are, however, available for smaller work. In the construction of the Bronx Valley sewer, mentioned above, portable Climax crushers, elevators and bin wagons were used and were moved from place to place where rock was being excavated from the trench.

Quantities of Sand, Stone and Cement.—As in the case of mortar the quantities of ingredients required per unit volume of concrete depend on the character of the sand and stone, the percentage of voids and the density as affected by the proportions of particles of different sizes in the mixture. The general laws relating to volumes and voids are thus stated by Taylor and Thompson in their "Concrete, Plain and Reinforced," second edition, page 160:

"(1) A mass of equal spheres, if symmetrically piled in the theoretically most compact manner, would have 26 per cent. voids whatever the size of the spheres, but by experiment it is found that it is practically impossible to get below 44 per cent. voids.

"(2) If a dry material having grains of uniform shape be separated by screens into grains of uniform dimensions, the separated sizes (except when finer than will pass a No. 74 screen) will contain approximately equal percentages of voids; in other words, a dry substance consisting of large particles, all of similar size and shape, will contain practically the same percentage of voids as a substance having grains of the same shape but of uniformly smaller size.

"(3) In any material the largest percentage of voids occurs with grains of uniform size, and the smallest percentage of voids with a mixture of sizes so graded that the voids of each size are filled with the largest particles that will enter them.

"(4) An aggregate consisting of a mixture of coarse stones and sand has greater density—that is, contains a smaller percentage of voids—than the sand alone.

"(5) By Fuller and Thompson's experiments, perfect gradation of sizes of the aggregate appears to occur when the percentages of the mixed aggregate passing different sizes of sieves are defined by a curve which approaches a combination of an ellipse and straight line.

"(6) Materials with round grains, such as gravel, contain fewer voids than materials with angular grains, such as broken stone, even though the particles in both may have passed through and been caught by the same screens.

"(7) The mixture of a small amount of water with dry sand increases its bulk. In the case of most bank sands the maximum volume—and hence the smallest amount of solid matter per unit of volume, that is, the largest percentage of absolute voids—is reached with from 5 to 8 per cent. of water."

In practice the effort is to obtain, so far as practicable, both for strength and impermeability, the densest mixture possible. The best experimental work on this subject has been done by W. B. Fuller and Sanford E. Thompson (Trans. Am. Soc. C. E., vol. lix, and Taylor and Thompson, "Concrete, Plain and Reinforced," to which the reader is referred).

Fuller gives detailed directions for analyzing aggregates by screening into different sizes, making analyses of these different sizes and combining, by the aid of curves plotted from the analyses, the different materials in such proportions as to obtain a curve of maximum density. It is usually impracticable to screen the aggregates into many sizes for the purpose of recombining them in proper proportions, but often by screening to three or even two sizes, combinations can be made to fit the theoretical mixture surprisingly well. If the particular sand and gravel to be used are already determined, Fuller gives the following method of proportioning by trial mixtures.

"Having determined the particular sand and stone which are to be used on any piece of work, a simple and accurate way of determining proportions is by actual trial batches of fresh material. For this it is only necessary to have good scales and a strong and rigid cylinder, say, a piece of 10-in. wrought-iron pipe capped at one end. Carefully weigh out and mix together on a piece of sheet steel or other non-absorbent material all the ingredients, having the consistency the same as is intended to be used in the work. Place these in the pipe, carefully tamping all the time, and note the height to which the pipe is filled. Weigh the pipe before filling and after being filled, thus checking the weight of material mixed. Throw this material away before it has time to set, and clean the pipe. Make up another batch, using the same weights of cement and water and the same total weight of sand and stone, but have the ratio of weights of the sand and stone slightly different from the first. Note whether, after placing, the height in the cylinder is less or more than was the height of the first batch, and this will be a guide to further similar mixes, until a proportion is found which gives the least height in the cylinder, and at the same time works well while mixing and looks well in the cylinder, all the stones being covered with mortar. This method, if carefully followed, will give very accurate results, but of course does not indicate, as does mechanical analysis, what other changes can be made in the physical sizes of the sand and stones so as to get the best available composition."

To what extent it is economical to go in the proper separation and combining of aggregates is, of course, impossible to determine except by a consideration of local conditions. It may be stated, however, that under certain conditions perfect grading of the mixture may result in saving 1/2 bbl. or more of cement per cubic yard of concrete, and equal strength will be attained.

Methods involving the determination of voids by running water into the aggregates give erroneous results and are no more accurate than the arbitrary selection of proportions such as 1 : 2 : 4 or 1 : 3 : 6 parts of cement, sand and stone respectively. This method is based on the theory that the voids in the stone will amount on an average to 50 per cent., and that the amount of mortar should be slightly in excess of this 50 per cent. The general laws governing the relations of the various constituents are thus summarized by Taylor and Thompson:

> "The strength and density of concrete are affected but slightly, if at all, by decreasing the quantity of the medium size stone of the aggregate and increasing the quantity of the coarsest stone. An excess of stone of medium size, on the other hand, appreciably decreases the density and strength of the concrete.
>
> "The strength and density of concrete are affected by the variation in the diameter of the particles of sand more than by variation in the diameters of the stone particles.
>
> "An excess of fine or of medium sand decreases the density of the mixture, but increases the strength, although in a slightly smaller ratio than the increase in the ratio of cement.
>
> "The substitution of cement for fine sand does not affect the density of the mixture but increases the strength, although in a slightly smaller ratio than the increase in the ratio of cement.
>
> "It follows from the foregoing conclusions that the correct proportioning of concrete for strength consists in finding, with any percentage of cement, a concrete mixture of maximum density, and increasing or decreasing the cement by substituting it for the fine particles in the sand or *vice versa*.[1]
>
> "In ordinary proportioning with a given sand and stone and a given percentage of cement, the densest and strongest mixture is attained when the volume of the mixture of sand, cement and water is so small as just to fill the voids in the stone. In other words, in practical construction, use as small a proportion of sand and as large a proportion of stone as is possible without producing visible voids in the concrete."

As indicating the amounts of materials necessary for concrete, under average conditions usually obtaining in sewer work, Table 63 is taken from a table in "Concrete, Plain and Reinforced," by Taylor and Thompson:

Mixing Concrete by Hand.—Concrete may be mixed by hand or by one of the various types of machine mixers. The relative economy in cost of the two can only be decided by a consideration of the size of, and conditions surrounding, the work. On small sewers the necessity

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[1] This very important law requires further tests for confirmation outside of the limits of the present tests.

TABLE 63.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF RAMMED CONCRETE, BASED ON A BARREL OF 3.8 CU. FT.

(Reproduced by permission from Taylor and Thompson's "Concrete, Plain and Reinforced," second edition)

Proportions by parts			Proportions by volume			Vol of mortar in terms of percentage of vol of stone, per cent.	Percentages of voids in broken stone or gravel														
							50 per cent.[1]			45 per cent [2]			40 per cent.[3]			30 per cent [4]			20 per cent.[4]		
Cement	Sand	Stone	Packed cement, bbl	Loose sand, cu ft	Loose stone, cu. ft		Cement bbl	Sand cu yd	Stone cu yd	Cement bbl	Sand cu yd	Stone cu yd	Cement bbl	Sand cu. yd	Stone cu yd	Cement bbl	Sand cu. yd	Stone cu. yd	Cement bbl.	Sand cu. yd	Stone cu. yd
1	2	3	1	7.6	11.4	75	1.89	0.53	0.80	1.81	0.51	0.76	1.74	0.49	0.74	1.61	0.45	0.68	1.50	0.42	0.63
1	2	3½	1	7.6	13.3	65	1.76	0.49	0.87	1.68	0.47	0.83	1.61	0.45	0.79	1.48	0.42	0.73	1.38	0.39	0.68
1	2	4	1	7.6	15.2	57	1.65	0.46	0.93	1.57	0.44	0.88	1.50	0.42	0.84	1.38	0.39	0.78	1.27	0.36	0.72
1	2	4½	1	7.6	17.1	51	1.55	0.44	0.98	1.48	0.42	0.94	1.41	0.40	0.89	1.28	0.36	0.81	1.18	0.33	0.75
1	2	5	1	7.6	19.0	47	1.47	0.41	1.03	1.39	0.39	0.98	1.32	0.37	0.93	1.20	0.34	0.84	1.10	0.31	0.77
1	2	5½	1	7.6	20.9	43	1.39	0.39	1.08	1.31	0.37	1.01	1.25	0.35	0.97	1.13	0.32	0.87	1.03	0.29	0.80
1	2	6	1	7.6	22.8	40	1.32	0.37	1.11	1.25	0.35	1.06	1.18	0.33	1.00	1.06	0.30	0.89	0.97	0.27	0.82
1	2½	3	1	9.5	11.4	87	1.72	0.61	0.73	1.66	0.58	0.70	1.60	0.56	0.68	1.49	0.52	0.63	1.40	0.49	0.59
1	2½	3½	1	9.5	13.3	75	1.62	0.57	0.80	1.55	0.55	0.76	1.49	0.52	0.73	1.38	0.49	0.68	1.29	0.45	0.64
1	2½	4	1	9.5	15.2	66	1.52	0.54	0.86	1.46	0.51	0.82	1.40	0.49	0.79	1.29	0.45	0.73	1.19	0.42	0.67
1	2½	4½	1	9.5	17.1	60	1.44	0.51	0.91	1.37	0.48	0.87	1.31	0.46	0.83	1.20	0.42	0.76	1.11	0.39	0.70
1	2½	5	1	9.5	19.0	54	1.37	0.48	0.96	1.30	0.46	0.92	1.24	0.44	0.87	1.13	0.40	0.80	1.04	0.37	0.73
1	2½	5½	1	9.5	20.9	49	1.30	0.46	1.01	1.23	0.43	0.95	1.17	0.41	0.91	1.07	0.38	0.83	0.98	0.34	0.76
1	2½	6	1	9.5	22.8	46	1.24	0.44	1.05	1.17	0.41	0.99	1.11	0.39	0.94	1.01	0.36	0.85	0.92	0.32	0.78
1	2½	6½	1	9.5	24.7	42	1.18	0.42	1.08	1.12	0.39	1.02	1.06	0.37	0.97	0.96	0.34	0.88	0.88	0.31	0.80
1	2½	7	1	9.5	26.6	40	1.13	0.40	1.11	1.07	0.38	1.05	1.01	0.36	0.99	0.91	0.32	0.90	0.83	0.29	0.82
1	3	4	1	11.4	15.2	76	1.42	0.60	0.80	1.36	0.57	0.77	1.30	0.55	0.73	1.21	0.51	0.68	1.12	0.47	0.63
1	3	4½	1	11.4	17.1	68	1.34	0.57	0.85	1.28	0.54	0.81	1.23	0.52	0.78	1.13	0.48	0.72	1.05	0.44	0.66
1	3	5	1	11.4	19.0	61	1.28	0.54	0.90	1.22	0.52	0.86	1.17	0.49	0.82	1.07	0.45	0.75	0.99	0.42	0.70
1	3	5½	1	11.4	20.9	56	1.22	0.52	0.94	1.16	0.49	0.90	1.11	0.47	0.86	1.01	0.43	0.78	0.93	0.39	0.72
1	3	6	1	11.4	22.8	52	1.16	0.49	0.98	1.11	0.47	0.94	1.05	0.44	0.89	0.96	0.41	0.81	0.88	0.37	0.74
1	3	6½	1	11.4	24.7	48	1.12	0.47	1.02	1.06	0.45	0.97	1.01	0.43	0.92	0.92	0.39	0.84	0.84	0.35	0.77
1	3	7	1	11.4	26.6	45	1.07	0.45	1.05	1.01	0.43	0.99	0.96	0.40	0.95	0.87	0.37	0.86	0.80	0.34	0.79
1	3	7½	1	11.4	28.5	42	1.03	0.44	1.09	0.97	0.41	1.02	0.92	0.39	0.97	0.83	0.35	0.88	0.76	0.32	0.80
1	3	8	1	11.4	30.4	40	0.99	0.42	1.11	0.93	0.39	1.05	0.88	0.37	0.99	0.80	0.34	0.90	0.73	0.31	0.82

[1] Use 50 per cent. columns for broken stone screened to uniform size. [2] Use 45 per cent. columns for average conditions and for broken stone with dust screened out. [3] Use 40 per cent. columns for gravel or mixed stone and gravel. [4] Use these columns for scientifically graded mixtures.

of frequent changes in the location of the mixer generally precludes the use of charging machinery, by which some economy is sometimes effected on large work, so that the saving in labor over hand mixing is only that due to turning and mixing the concrete. Against this must be placed the interest on the original cost, depreciation and operating expenses of the machine mixer. Where only a small quantity of concrete is to be mixed per day, these charges may be greater than the cost of mixing by hand.

At Harrisburg, Pa. (*Eng. Rec.*, Oct. 15, 1904), experiments with a machine mixer in a section requiring 0.34 cu. yd. of concrete per foot showed no economy by the use of a machine. At Louisville, Ky., where a large number of concrete sections varying in size from 2 to 15 ft. in diameter were built in 1907 to 1910, a very large proportion were constructed by the aid of concrete mixers, even down to those about 4 ft. in diameter. It is questionable, however, whether on these smaller sizes there was any economy over hand mixing. As a rough general statement it may be said that very often machine mixers may be found economical where the amount of concrete to be mixed is in excess of 20 cu. yd. per day. This, of course, assumes that working spaces are sufficient to permit efficient handling of the machine.

The process of mixing by hand may be performed in a number of different ways. Sand and cement may be mixed dry, spread upon the stone evenly and water applied, after which the mixture is turned, or the cement and sand may be made into mortar which is spread upon the stone and the mass turned and mixed. In the latter case the mortar is mixed separately in the mortar bed, the cement and sand being mixed dry until they are thoroughly incorporated and the mixture is of an even color throughout. Water is then added and the mixture still further turned over with shovels or stirred with long-handled hoes, before spreading on the stone.

For measuring the materials it is convenient to provide bottomless boxes of proper sizes, handles being provided at the corners by which they may be lifted after being filled. Under some conditions, however, it may be possible to calibrate the wheelbarrows and thus proportion the amount of sand and stone by taking a specified number of wheelbarrow loads of each. The batch which has been found most convenient and customary to mix is one which takes a barrel of cement and amounts to 20 cu. ft., more or less. It is not usual to measure the cement separately, but the amount both as to volume and weight which a barrel is assumed to contain is specified. As there is a great variation in the weights of cement per unit of volume, depending on whether it is weighed loose or packed, it is customary to assume and specify that 100 lb. of cement equals 1 cu. ft., and that one barrel contains 3.8 cu. ft.

In mixing the concrete, two men face each other on opposite sides of the mixing board and the mass is spread out in a thin layer on it. Then with square-pointed shovels, one man working right-handed and the other left-handed, they push the shovels along the platform under the piles, lift a shovelful and turn it over with a spreading motion, drawing the shovel at the same time toward themselves. By this method of operation a ridge of concrete is soon formed parallel to the original mass and 2 or 3 ft. away from it. This ridge is then handled in the same way by two more men, thus giving it a second turn. After the whole mass has been thus turned over twice, two of the men turn the material a third time back into a position near its original place. With a large gang a pile may be attacked from two sides, eight men thus being occupied in mixing the material. Usually three complete turns of the whole mass by skilful men are sufficient for proper mixing, but not when the work is done without proper spreading of the materials by the shovelers. A gang of about 16 men, depending on the distance the material must be wheeled, the difficulty of placing, etc., will mix and place about 25 cu. yd. per day of 10 hours.

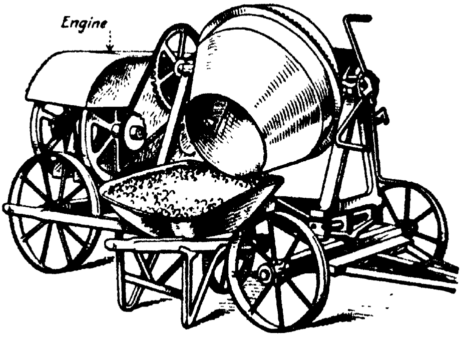

FIG 123 —Gasoline-driven mixer (Little Wonder).

Machine Mixing.—Mechanical concrete mixers are of two general classes, continuous and batch. There is a further differentiation as to the manner of mixing, as by paddles, gravity or rotation. By far the greater number of mixers used in sewer work consist of the rotary batch type, which is either discharged by tilting or by introducing a chute which intercepts the falling concrete and carries it out. Fig. 120 shows one of the tilting mixers and Fig. 121 one of the stationary mixers with discharging chute. Another type consists of a cube rotated so that a line through two opposite corners maintains a horizontal position. About 1910, a demand for small mixers arose and was met by a number of light machines, one of which is shown in Fig. 123. It weighs only 1450 lb. with the truck and 2-1/2-h.p. gasoline engine and mixes 5 cu. ft. of concrete in a batch.

Mixers of the batch type are usually charged by hand, either by the use. of runways and wheelbarrows where the charging hopper is not too high, or mechanically by filling boxes, Fig. 122, which are lifted from the ground and dumped into the mixer.

Continuous mixers are operated by paddles which stir the material in a trough and push it constantly toward one end. The materials are handled either by being spread out in proper proportion on a platform and then shoveled into the mixer, or by men shoveling them in proper proportions, from piles of cement, sand and stone, that is, a 1 to 2 to 4 mixture would require one man shoveling cement, two sand and four stone, thus maintaining a constant proportion of ingredients.

In one type of gravity mixer the materials, previously arranged in layers of stone, sand and cement, are shoveled into a long chute-like device crossed by bars at intervals for breaking up the materials, which toss them about and against the sides, water being introduced at the same time. In another type cone-shaped hoppers with openings closed by gates are located one above the other, the materials being discharged from one to the other and mixed by mingling together in their passage.

A portable gravity mixer known as the Hains-Weaver has been used to some extent on sewer work. This consists of four iron hoppers hung one below the other by chains, each hopper being provided with a gate at the bottom. The sand, stone, cement and water are placed in the first hopper, after which the gate is opened, allowing the contents to flow into the second hopper, its gate then being opened and so on. The action of the mixer is somewhat like that of the sand in an hour glass, the materials from the sides flowing toward the center and thence downward. For concrete of fairly wet consistency, such as is often desirable in sewer work, this type of mixer apparently works well. When too much water is added there is a tendency for the water and fine material to run through rapidly, leaving the stone to follow. For dry mixtures the mixing is liable not to be as complete as desirable.

This type of mixer was used on a 4 ft. 3 in. by 5 ft. sewer in Boston where the conditions were somewhat unusual. This sewer was being built through a narrow alley where the trench took up practically the full working space. A cableway was installed with the towers erected in streets at the ends of the alley. The mixer was hung from an elevated wooden portable platform carried by a framework the legs of which rested on the trench braces. A number of additional hoppers similar to those composing the mixer but provided with legs so that they could be brought to rest over the top of the mixer, were used for transporting the concrete materials, including water, which were placed in them in the street at one end of the alley. This sewer was built in three operations, and two frameworks for supporting the mixer were provided, each in turn being lifted by means of the cableway and placed about 15 ft. forward of the one in use.

Materials may be measured in ordinary steel wheelbarrows but barrows with high sides, Fig. 124, allow of more accuracy of measurement and carry larger quantities of wet concrete. The ordinary barrow holds but a small quantity, as the concrete, when very wet, assumes a horizontal position so that but small space is available if the concrete is to be prevented from running over the sides and ends when the barrow is lifted.

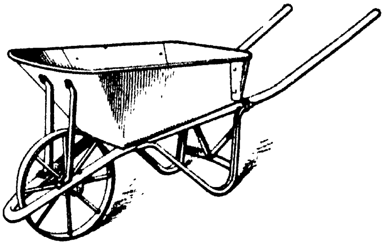

FIG. 124.—Concrete wheelbarrow (Sterling).

On this account two-wheel carts with high sides, Fig. 125, are sometimes used, but they require a wide runway and may be too heavy when filled unless the ground or runway is level.

Under some conditions an industrial railway may be laid beside the trench and side dump cars of the type shown in Fig. 126 may be used, discharging their contents into chutes which convey it to the forms. Where a single permanent mixing plant can be made to serve a large piece of work, narrow gage railways are often desirable for several purposes, and in order to limit the variety of cars needed it may be advisable to use flat instead of dump cars and to carry the concrete in buckets, which can be handled at the trench by derricks or otherwise. This will involve more labor in handling concrete but the expense of shifting a chute in the trench may be avoided.

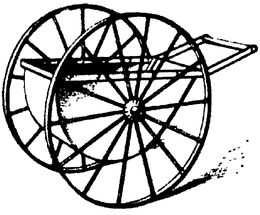

FIG. 125.—Concrete buggy (Ransome)

Where the concrete is delivered by derricks, cranes or cableways, it must be transported in buckets, of which many varieties are in use. Some of them are emptied by tripping a catch, which allows them to turn over, discharging the concrete with a wide-reaching splash. Where more accurate placing of the concrete is required, a bucket with a hinged bottom is used, and where very accurate placing is needed, as in walls, the form shown in Fig. 127 is particularly serviceable, as the discharge of the concrete is kept under close control. On large work where the introduction of labor saving machinery has proved economical and sufficient working space was available, much ingenuity has been expended in the design of concrete mixing and transporting machinery.

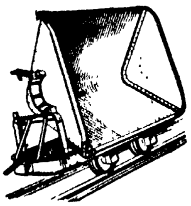

FIG 126 —Concrete car (Wiener)

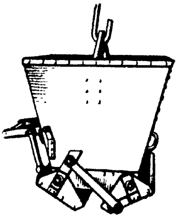

FIG 127 —Bottom-dump bucket (Stuebner)

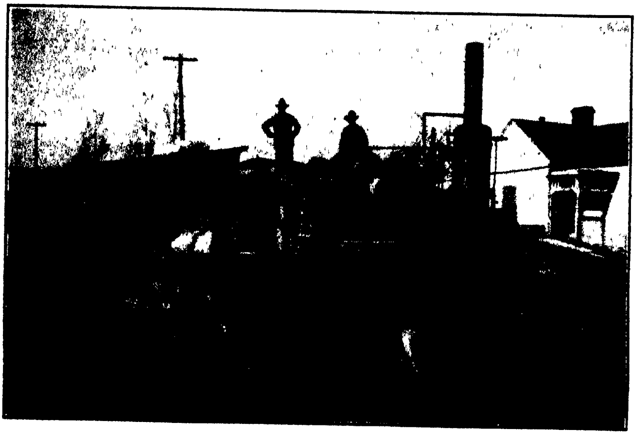

FIG. 128.—Concrete plant over trench, Louisville.

An interesting equipment was installed upon Section B of the Southern outfall sewer at Louisville, Ky. It consisted, primarily, of a concrete mixer mounted upon a standard gage car, and a locomotive crane, both being moved along the trench as the work progressed. The sand and gravel were dumped beside the trench, shoveled into a bucket which was hoisted by the crane and discharged into suitable hoppers, mounted on the car above the concrete mixer. A water tank was placed on the car at such an elevation that the water would run by gravity to the mixer, operated by a steam engine which, with its boiler, was also mounted on the car. At one end of the car an enclosure was built for storing cement. As the concrete was mixed it was dumped directly into a hopper from which it flowed through chutes into the trench where required. Upon Section D of the sewer, a car spanning the trench was used for conveying the concrete mixing machinery, as shown in Fig. 128. This car also carried a house in which the cement was stored. The materials were brought to the mixer in wheelbarrows and after the concrete was mixed, it was discharged into a hopper and through troughs into the forms.

An illustration of the extent to which special equipment and machinery for the mixing and handling of concrete may be used upon sewer work is furnished by the construction of the sewer at Classon Point, in the Borough of the Bronx, New York City, described in "*Municipal Journal*," vol. xxxv, p. 821. At the upper end the sewer is 7 ft. wide and at the lower end of the single barrel structure it is 12 ft. 6 in. wide. Below this point the sewer is a double barrel structure, each barrel ranging in size from 8 ft. 3 in. to 11 ft. 3 in. wide. The entire length of the sewer is about 9100 ft. Near the outlet a dock was provided from which a construction track extended throughout the length of the work. Upon the dock small elevated bins for sand and gravel were constructed. These are filled by means of a derrick from scows which were loaded at the gravel bank with sand and gravel in the proportions required for the concrete. The materials for the concrete were conveyed from the dock to the work in buckets upon flat cars. The cars were placed under the small bins from which charges of gravel and sand were drawn and automatically measured, upon which the necessary quantity of cement was placed. Two cars, each containing six buckets, were then hauled to the work, hoisted and discharged into a Hains gravity mixer, mounted upon a tower built upon a wide-gage car. After the concrete had passed through the mixer into a bucket placed upon the ground, it was raised up a steel tower on the same car to the necessary height and discharged into a loading hopper, from which it was drawn into a U-shaped trough, through which it flowed to a second hopper, whence it was discharged by troughs into the forms. The plant was so arranged that the discharging hoppers could be placed at any desired height and the concrete distributed over a considerable area by means of swivel joints connecting the two chutes. The cars carrying the engines and mixing and discharging towers were moved along the side of the trench on rails, as the work progressed.

It is of the utmost importance to estimate carefully the quantity of concrete required, the expense of handling it by different methods and the cost and operating charges of plant before deciding what equipment should be provided for a given undertaking. While mechanical equipment will prove advantageous if the quantity of concrete to be handled is large and the plant can be kept in operation a relatively large proportion of the time, it is easy to provide a plant so complicated and expensive that its operation more than offsets the saving in cost of mixing and placing the concrete by simpler methods. Upon small sewer work, it is often less expensive to mix and place the concrete by hand than to employ even relatively simple machinery, and the use of complicated handling and mixing machinery upon small work is rarely justified. It is probably true also upon most sewer work that relatively little money is made or lost in the handling of concrete in comparison with that which may be made or lost in the handling of the excavation.

Placing Concrete.—Upon small work, where excavations are shallow, it will usually be most satisfactory to shovel the concrete into the forms from the mixing bed. Where the work is deep and it is not convenient to place the mixing bed over it, the concrete can be conveyed from the mixing bed to the forms through chutes, which may be made of wood lined with sheet iron, or preferably entirely of sheet iron. Such troughs are frequently U-shaped, although, and especially where they must be placed in a nearly vertical position, they may be made nearly cylindrical in form. In either case they should be so constructed as to telescope, the lower end of the upper trough fitting into the upper end of the trough below. It will usually be found convenient to provide a metal hopper at the top, into which the concrete may be thrown or dumped and from which it will flow into the troughs.

Concrete should be made of such a consistency that it will flow readily through a trough inclined 1 ft. in 3 ft., and at least this inclination should be provided, as concrete will not flow readily through troughs laid upon a flatter slope. It is necessary many times to hang the troughs or pipes upon a much steeper slope and difficulty is often experienced when the angle of inclination is at or somewhat more than 45 deg. by the tendency of the stone, and particularly of rounded gravel, to separate from the mortar in passing through the trough or pipe. Where the angle of inclination is nearly vertical, this tendency is again reduced. Where there is a decided tendency for the stone to separate from the mortar, it may be necessary to catch the concrete in a box and re-mix it before finally placing it in the forms. If this is not done, care must be taken to prevent "pockets" of cobbles or broken stone in which there is insufficient mortar and fine aggregate.

Concrete is now usually mixed very wet and does not require tamping, but does need more or less spading and slicing with thin metal blades. These are of assistance in working the concrete through reinforcement and for scraping and prying the larger stones away from the forms, so as to leave a good mortar finish when the forms are removed. Two or more men, depending on the size of the work, are required for placing and cutting the concrete, and one man, when wheelbarrows are employed, to assist in emptying them into the chutes.

Careful consideration should be given to the best method of constructing concrete sewers Small circular sewers, perhaps up to a diameter of 4 ft., can in many cases be advantageously built in one operation, full cylindrical forms (described in Chapter XV) being placed before any concrete is put into the trench. Upon larger sewers there is a great variety of forms available for use, some being made of wood and others of steel. Much ingenuity may be exercised in the design of large forms to reduce the cost of labor in removing and carrying them forward and resetting them.

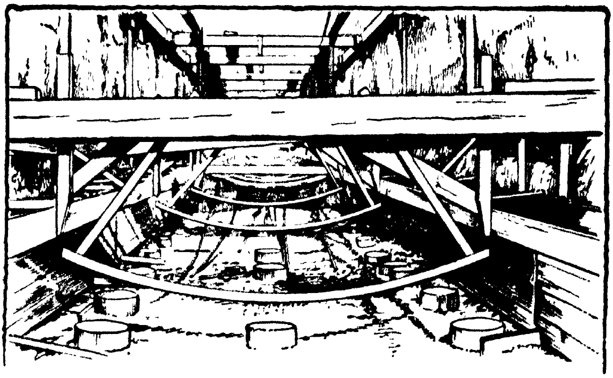

FIG. 129.—Templates to which invert was screeded, Louisville

Sewers more than 4 ft. in diameter are generally built in two, three, or more operations. The invert is first placed for a considerable distance. Upon this the side walls are built and after these become set the arch is turned. This method of progressive construction requires that a considerable length of trench be kept open at all times for concreting, and as time is required for the concrete to become thoroughly set and acquire sufficient strength so that the forms may be removed, it is a source of considerable delay which should be taken into consideration in planning the rate of progress to be attained.

Inverts are generally laid and screeded to templates. In some cases the concrete is placed in alternate blocks, from 8 to 10 ft. in length, between bulkheads. Where the concrete is placed continuously it is necessary to provide templates at frequent intervals, which may conveniently be constructed of 1/2 × 1-1/2-in. steel on edge and hung from the bracing overhead, Fig. 129. As the concrete is screeded these templates are moved forward.

Where the concrete of which the invert is constructed is very wet and contains a large quantity of mortar, it may be possible to so work it as to bring the mortar to the surface and provide a satisfactory and smooth invert surface by screeding. If the concrete is lean or dry it may be necessary to use a small quantity of mortar to secure a smooth finish, usually not more than 1/2 in. This, of course, should be applied before the concrete has acquired its initial set.

If good concrete work is to be secured it is absolutely essential to have watertight, well-made and accurate forms, and to mix the concrete of the proper consistency. If these two points are given careful attention, little difficulty should be experienced in providing a satisfactory concrete structure.

Placing Reinforcement.—In the construction of reinforced concrete sewers, placing and holding the reinforcement in its proper position is a troublesome as well as an important matter. The method of doing this largely depends upon the position of the metal and the ingenuity of the constructor. For small sewers, 3 ft. or less in diameter, which may be built in one operation, as described in Chapter XV upon "Forms and Centers," reinforcement is not usually required. If, however, for special reasons reinforcement is necessary, construction in a single operation is generally impracticable. This is particularly the case where expanded metal or woven fabrics of fairly coarse mesh are used. The fabric acts as a screen, preventing the free flow of concrete around the forms. In such cases, as with larger circular sewers, it is desirable to lay part of the invert under the more inaccessible part of the form, by means of templates and screeds. Part of the reinforcing material, bent to shape and extending above the springing line, is held in proper position by fastening it to longitudinal timbers on either side of the trench, and, if necessary, it is also supported by blocks underneath it, removed as the concrete reaches them. When the invert is more or less flat, the concrete may be first placed up to the position of the steel, which is then put in position and the concreting continued, or the whole system of reinforcement may be first placed in position and held by blocking and fastening to the trench braces, before any concrete is placed. This latter method, shown in Fig. 130, assures the proper location of the steel. After the sewer is completed to the springing line and the centers placed, the arch steel is set and fastened by wiring it to the projecting ends of the invert steel, a proper space between the centers and the steel being maintained, if necessary, by blocks which are removed as the concrete reaches them.

Much of the success in the proper placing of the reinforcing steel depends upon bending it to the correct shape before it is lowered into the trench. This may be done on the bank by the aid of templates and a bar or tire bending machine, or, in case of large quantities of a particular shape, the steel may be bent at the mill before shipment. In the construction of a concrete sewer in the Borough of Queens, N. Y., the rods were bent on the bank by unskilled labor. A heavy platform was provided, to which were nailed pieces of 4 × 4 in. timbers 2 ft. long. These were nailed at proper points determined by trial, and the steel bent around them.

When the arch only is to be reinforced, short pieces of steel may be left embedded at proper points, with their ends projecting above the invert masonry at the springing line, to which the arch steel, which is held above the centers by blocks at the crown, may be fastened. In the sewer construction mentioned above, holes were left in the green concrete of the side walls, into which the ends of the arch steel were grouted after the arch centers had been placed.

During construction it should be borne in mind that while the steel may be easily lifted out of wet concrete, it is almost impossible to force it in. Thus in forming the arch when flexible material is used, it may be easily kept away from the inner surface by lifting, but if lifted too high it is almost impossible to force it back again to its proper location.

WATERPROOFING

Permeability of concrete is more or less dependent upon a number of factors. It may be lessened by increasing the proportion of cement to other ingredients, by the use of sand and gravel rather than crushed stone and screenings, by proper grading of the aggregates, by making the mixture quite wet, and by increasing the thickness of the concrete.

It is neither practicable nor economical to make sewers wholly impervious to water, as is sometimes done in the case of other underground structures which are not used for carrying water. The use of carefully graded mixtures rich in cement, mixed wet and effectively worked and spaded into place, is the extent to which it is generally considered economical to go. Such precautions, where the head is slight and where the concrete shell is of considerable thickness, will result in practically impervious concrete. Under certain conditions, however, where the sewers are laid in wet trenches and the head of water outside is considerable, and particularly where the concrete section is a thin one, it is desirable to take some special precautions to prevent excessive leakage.

At Fitchburg, Mass. (report of David A. Hartwell, Chief Eng., Sewer Commissioners, 1912) where the intercepting sewer was built in a water-course, the concrete walls were made 9 in. instead of 6 in. thick and reinforced with longitudinal steel rods to prevent contraction cracks. At Louisville, Ky., at places (report Sewer Commissioners, 1910) where large amounts of ground water were encountered, part of the sand used in making the concrete was replaced with 10 per cent. of fine molding sand mixed with some clay. Tests showed that this reduced the leakage to one-fifth of that obtained with an ordinary 1:2:4 mixture, and below that obtained with a mixture graded as perfectly as possible.

Various other mixtures, some of a proprietary character, have been used to decrease permeability. Generally these consist of fine earthy material which fills the interstices in the concrete, or fine material which by its nature repels water, or a combination of both. The fine sand just mentioned belongs to the first type. Clay is also effective, particularly with lean mixtures, say 1 part cement to 3 parts or more of sand. With richer mixtures, its value is not so apparent and it decreases the strength considerably, as in this case the interstices of the sand are already well filled with cement. Alum and soap, mixed in the proportion of 1 part alum to 2.2 parts hard soap, reduce permeability, but they also considerably reduce the strength of the resulting concrete. The alum may be mixed with cement dry and the soap dissolved in the water to be used for gaging. Or the materials may be dissolved in the water separately and mixed just before the concrete is made. As water will only dissolve about 3 per cent. by weight of hard soap, the proper proportions to be mixed with the water are 1-1/2 per cent. alum and 3 per cent. soap. Tests show that this mixture may reduce the strength of the concrete about 20 per cent. Lime and soap in the proportions of 1 to 12, or 1/4 per cent. lime to 3 per cent. soap, to the weight of water, have also been used with success. Hydrated lime (*Eng. Cont.*, July 15, 1908, Sanford Thompson) has been effectively used in the following proportions:

8 per cent of weight of cement, 1:2:4 concrete
12-1/2 per cent of weight of cement, 1:2-1/2:4-1/2 concrete.
16 per cent of weight of cement, 1:3:5 concrete.

Soap and alum have been used for many years in the Sylvester process of waterproofing masonry by successive alternate surface applications of solutions of these materials. (*Trans. Am. Soc. C. E.*, vol i, p. 203.) The early use of these substances as ingredients in mortar is difficult to trace. In 1900 Gen. W. L. Marshall added 3/4 lb. of alum to each cubic foot of sand and 3/4 lb. of soft soap to each gallon of water for 1:2-1/2 mortar for work in New York harbor. In 1903 the subject was discussed at the convention of the American Society of Civil Engineers.

At Louisville, Ky. (report Commissioners of Sewerage, 1910) experiments were made to determine the most effective waterproofing compound to use on certain sewers to be built in wet ground. Tests were made of specimens of concrete 10 in. in diameter and 4 in. thick. These blocks were placed between iron castings, bolted firmly together in such a way as to allow the application of water under different pressures to a surface 6 in. in diameter. One sample of concrete was proportioned to form a theoretically perfectly graded mixture; another an ordinary 1 :2 :4 mixture, and another a 1 :2 :4 mixture to which varius waterproofing compounds of a proprietary nature were added. Table 64 gives the results of these tests.

Table 64.—Seepage in 7 Hours through Concrete with Various Waterproofing Treatments, under 15 Lb. Pressure

(Report Commissioners of Sewerage, Louisville, Ky., 1907–1910, p. 88)

Specimen	Cubic inches per square inch	Cubic centimeters per square centimeter	Gallons per square foot	Total seepage in cubic centimeters
Perfect mixture	1.56	3.95	0.97	721
Concrete, 1-2-4	6.47	16.45	4.04	3,000
Concrete with 5 per cent. clay	0.86	2.18	0.54	398
Concrete with 10 per cent. clay	0.12	0.31	0.08	56
Concrete with 5 per cent. fine sand	4.94	12.55	3.08	2,290
Concrete with 10 per cent fine sand	1.22	3.10	0.76	565
Concrete with 4 per cent. hydrated lime	0.72	1.82	0.45	332
Concrete with 6 per cent. hydrated lime	0.24	0.61	0.15	112
Concrete with 8 per cent. hydrated lime	0.11	0.27	0.07	49
Concrete with 2 per cent. Medusa	0.97	2.47	0.61	450
Concrete with 4 per cent. Medusa	0	0	0	0
Concrete with 4 per cent. Maumee	0.24	0.60	0.15	110
Concrete with McCormick	0.17	0.44	0.11	80
Concrete with Ceresit	2.00	5.09	1.25	928
Concrete with 4 per cent Toxement	0	0	0	0

Note.—Where very fine sand and clay were used they replaced an equal amount of Ohio River sand. Where hydrated lime, Medusa, Maumee and Toxement were used, the amount added was a definite proportion of the quantity of cement used, but the quantity of cement was not reduced. The McCormick compound was furnished already mixed with the cement and was said to have been mixed just before grinding. The Ceresit was substituted for a portion of the water and in the proportion of one to twenty. The dry waterproofing compounds and the lime were added to and thoroughly mixed with the cement before wetting.

TABLE 65.—RESULTS OF TESTS TO DETERMINE EFFECT OF WATERPROOFING MATERIALS UPON THE TENSILE STRENGTH OF NEAT AND MORTAR (1 : 3) BRIQUETTES

Waterproofing materials added	How added	Per cent. added	Tensile strength			
			Neat		Mortar 1-3	
			7 days	28 days	7 days	28 days
McCormick "A," St. Louis	Combined with cement at mill	.....	797	740	205	307
McCormick "B," local	Combined with cement at mill	......	513	577	199	220
Ceresite	In place of water	5.0	642	669	311	375
Molding sand	In place of sand[1]	5.0	698	743	176	368
Molding sand	In place of sand	10.0	636	642	177	510
Hydrated lime	Added directly to dry cement.	5.0	749	651	387	511
Hydrated lime		10.0	608	635	371	505
Clay	In place of sand[1]	2.5	753	737	235	344
Clay	In place of sand	5.0	718	912	221	401
Clay	In place of sand	7.5	644	802	344	327

[1] In the case of the neat briquettes the amount of sand and clay added were percentages of the dry cement.

Tests were also made to determine the effects of these various compounds on the strength of neat cement and mortar, with the results given in Table 65. As a result of these experiments it was decided, as mentioned above, to use 10 per cent. of fine molding sand with some clay in substitution for an equal amount of ordinary sand.

The report of the Committee on Waterproofing Materials, of the American Society for Testing Materials (1913), states the following among its conclusions:

> "That the majority of patented and proprietary integral compounds tested have little or no immediate or permanent effect on the permeability of concrete and that some of these even have an injurious effect on the strength of mortar and concrete in which they are incorporated.
>
> "That the permanent effect of such integral waterproofing additions, if dependent on the action of organic compounds, is very doubtful.
>
> "That in view of their possible effect, not only upon the early strength but also upon the durability of concrete after considerable periods, no integral waterproofing material should be used unless it has been subjected to long-time practical tests under proper observation to demonstrate its value, and unless its ingredients and the proportions in which they are present are known.
>
> "That in general more desirable results are obtained from inert compounds acting mechanically than from active chemical compounds whose efficiency depends on change of form through chemical action after addition to the concrete.

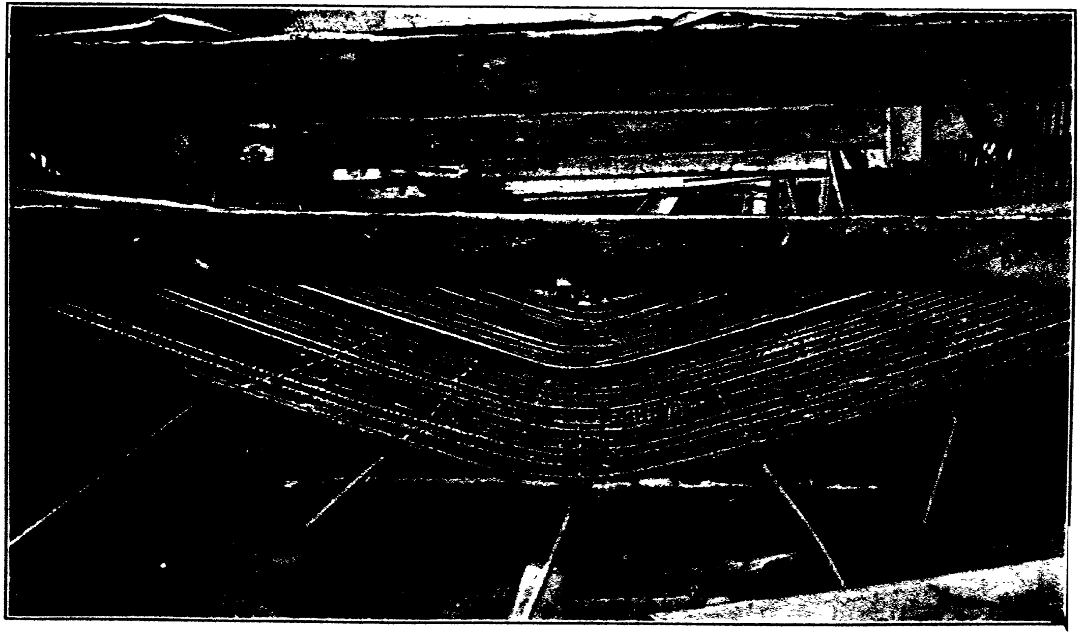

FIG. 130.—Supports for reinforcement in invert and side walls, Louisville.

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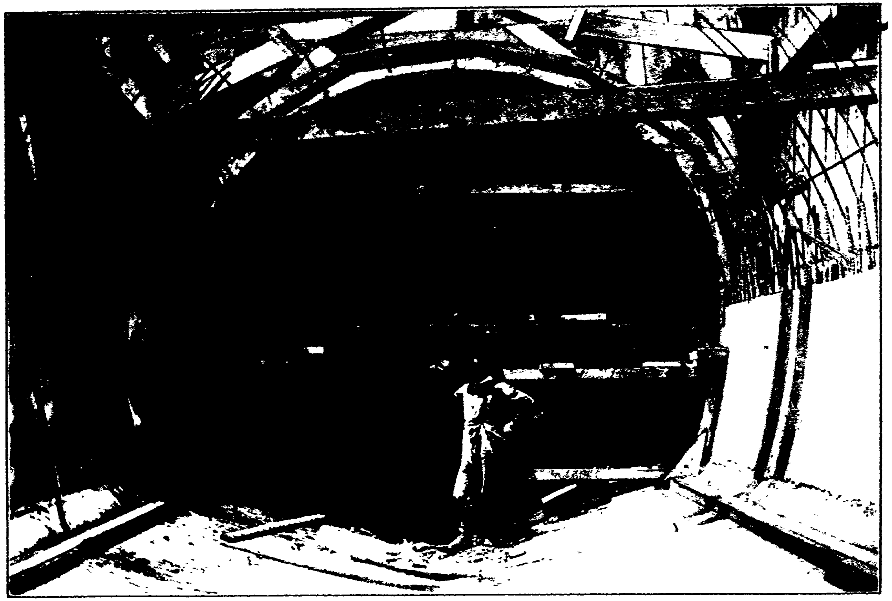


Fig. 131.—Joint used in a large sewer, Louisville.

"That void-filling substances are more to be relied upon than those whose value depends on repellent action.

"That, assuming average quality as to size of aggregates and reasonably good workmanship in the mixing and placing of the concretes, the addition of from 10 to 20 per cent. of very finely divided void-filling mineral substances may be expected to result in the production of concrete which, under ordinary conditions of exposure, will be found impermeable, provided the work joints are properly bonded and cracks do not develop on drying, or through change in volume due to atmospheric changes, or by settlement.

"So far the committee has considered only concretes of the usual proportions, namely, those ranging from 1 cement, 2 sand and 4 stone to 1 cement 3 sand and 6 stone. It has been suggested that impermeable concretes could be assured by using mixtures considerably richer in cement. While such practice would probably result in an immediate impermeable concrete, it is believed by many that the advantage is only temporary, as richer concretes are more subject to check cracking and are less constant in volume under changes of conditions of temperature, moisture, etc. Therefore, the use of more cement in mass concrete would cause increased cracking, unless some means of controlling the expansion and contraction be discovered. With reinforced concretes the objection is not so great, as the tendency to cracking is more or less counteracted by the reinforcement."

The low-level intercepting sewer at Baltimore was waterproofed by the membrane method and bituminous material was generally used in making the joints of the sanitary sewers leading to it, in order to reduce the rate of infiltration of the ground-water into the system. All the sewage collected by this intercepter must be pumped, as explained in Volume I, and it was decided that the additional cost of waterproofing sewers laid in very wet ground was justified by the probable reduction in the pumpage resulting from it. The average bid price on 8-in. sewers with bituminous joints was about 5 cents per foot above that for cement joints. The intercepter was below the level of mean low tide for 12,035 ft. and was generally within 100 to 300 ft. of the harbor. The bottom of the trench was in water-bearing gravel. No leakage test of the entire intercepter was ever made, but on a 3600-ft. section from 74 to 84 in. in diameter, the infiltration was practically nil, according to Chief Eng. Calvin W. Hendrick. The general method of waterproofing the sewer was as follows:

After the concrete for the invert and sides had set and become dry, it was covered up to the springing line of the arch with a coating of hot pitch, the contractor being permitted to use coal-tar pitch, refined natural asphalt, or asphalt made from petroleum. On this pitch a layer of burlap was laid at once and pressed into it firmly, so as to insure a good bond. The burlap was required to weigh 10 oz. per square yard, or Siastex waterproofing fabric weighing 12 lb. per 100 sq. ft. could be used in place of it. This layer of burlap was covered with hot pitch, another layer of burlap laid, and another coating of hot pitch applied. The brick lining was laid on this membrane. In constructing the arch, a single ring of brickwork was first laid, its back was waterproofed as described for the invert, and the concrete backing placed. Burlap was left projecting from the walls to overlap that of the arch, so as to keep the entire membrane integral.

WORK JOINTS

Concrete contracts during setting and also expands and contracts with temperature and moisture changes. In thin walls this property tends toward the formation of cracks about every 30 ft. If, however, longitudinal reinforcement is used, these cracks may be prevented, or rather so distributed through the length of the wall as to be invisible. In some concrete structures it is customary to leave joints at specified intervals which will open, thus preventing the formation of haphazard cracks. In structures carrying liquids under pressure these joints should be made water-tight. In sewerage work, however, the location of joints is not governed so much by considerations of expansion and contraction as by the exigencies of the work which necessitate the formation of joints at the end of each day's run. As for the matter of permeability, it is generally not attempted to make these joints in sewers absolutely water-tight, as is sometimes done in the case of water conduits operating under internal pressure or subways subject to external hydrostatic pressure. Reasonable precautions should be taken, however, to prevent infiltration and such measures as the adoption of effective methods of construction and the securing of high-grade workmanship are justified.

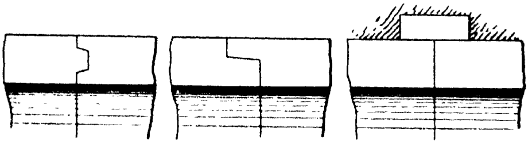


FIG 132 —Types of joints in sewers

Note —In the second form of joint, the midface or longitudinal surface of the joint, between the two circular or transverse surfaces, should be inclined about 1 to 12, giving a slightly conical shape to this part of the joint, in order to prevent any injury to the concrete in withdrawing the forms. The lap should be less than the thickness of the half section

Cracks and leaks are likely to develop at the planes where old and new concrete are joined, due to the weakness of the bond, and special precautions are required at these places. Where the invert and arch are built separately, it is customary on the completion of concreting the invert, to ram into the green concrete slightly beveled strips of timber from 2 to 6 in. wide, depending upon the width of the joint, which on removal leave grooves. These pieces should be braced down to prevent them from floating. Where the joint plane is of considerable width two parallel grooves may be thus formed. It is necessary to have such timbers beveled smooth and well lubricated, so that they may be removed without injuring the partially set concrete.

The vertical joints may be similarly formed, by fastening pieces of wood to the bulkhead placed at the end of the section. In some cases it may be desirable to fasten these pieces lightly to the bulkhead, by bolts or nails driven in from the outside, so that the bulkhead may be removed first, and the groove formers later. Otherwise, if both are moved at one operation, portions of the concrete may be broken off. When arch, side walls and inverts are constructed separately, the end of the day's run, or the joints, should be brought to the same vertical plane, otherwise one of the joints may open and a crack form opposite it all the way around the sewer.

A scarf joint may be formed by building up the end of the sewer forms so as to make an inset or rabbet when the form is removed, concrete being forced into the space left when the next section is placed. On the aqueduct constructed by the Board of Water Supply of the City of New York, where great precautions were taken to provide water-tight work, key blocks were first laid at specified intervals and coated with cold water paint, to prevent adhesion when contraction or expansion of the invert took place. Such elaborate precautions are, however, hardly justified in ordinary sewer work. Fig. 131 shows the joint in a large Louisville sewer, and Fig. 132 gives three types of joints.

Care must be taken to have the surface of the old concrete clean and rough and wetted, before placing the fresh concrete on it. A thin layer of rich mortar placed on the old surface just before concreting is started will also aid in forming a bond to the old work. This is most commonly accomplished by thoroughly washing with a stream of water under pressure and brushing with wire brushes. Sometimes the surface of the old concrete is roughed by picking or pointing and under exceptional conditions the surface of the concrete may be roughened, eaten or etched by the use of dilute muriatic acid. Needless to say, acid must be thoroughly washed off before any additional concrete is laid. Fresh concrete may be scratched and scored with a sharp tool to roughen it, and should be covered with boards to prevent dirt and débris from the street or sides of the trench from falling into it. In constructing sewers in San Francisco high winds carried great quantities of dust into the trench, which could not be removed from the fresh concrete by the use of water and brooms in the usual way. Various expedients were tried and finally fire hose attached to a nearby hydrant, operated under full pressure, was successful in cleaning off the dirt.

. PLACING CONCRETE IN FREEZING WEATHER

Natural cement concrete may be ruined by freezing before it has set, but experiments indicate that Portland cement concrete of good quality, which has been frozen, will ultimately obtain full strength if opportunity is given it to set after thawing and before attempting to remove the forms. It does not set any, however, while frozen, so that no structure of frozen concrete should be loaded nor should forms and supports be removed until the material has had an opportunity to thaw and set. For this reason it is impracticable to build sewers in cold weather unless precautions are taken to prevent freezing and to allow the concrete to set so that backfilling may be placed within a reasonable time.

At Louisville, Ky., no concreting was allowed at temperatures below 24° F., all materials had to be heated when the temperature was between 24° and 32° and only water was required to be heated when the temperature was between 32° and 35°.

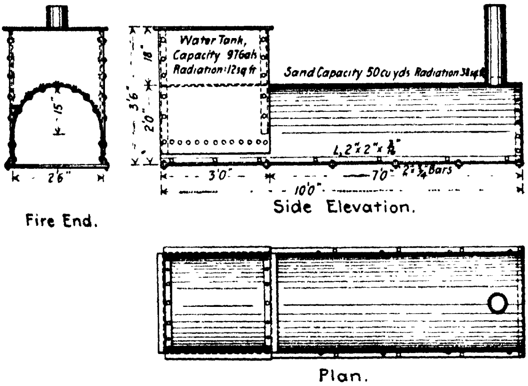


Fig. 133.—Device for heating concrete materials.

Concrete made of heated materials, placed quickly in forms, covered with boards and tarpaulin or straw, will set satisfactorily when the temperature is a number of degrees below freezing. Where steam is available, materials may be heated by circulating the steam through coils of pipe over and around which sand and stone may be placed, the exhaust being discharged into water barrels to heat the water. Or the sand and stone may be warmed by ordinary steel heaters. A heater of this type (*Eng. News*, March 19, 1903) with an attached provision for warming the water, is shown in Fig. 133.

The placing of concrete in freezing weather is obviously more expensive and uncertain than in warmer weather. Frozen dirt has much the same appearance as set concrete, making it difficult to discriminate in its removal. Even if the materials are kept from freezing, concrete gains strength only slowly in cool weather and it is necessary to keep the forms in place considerably longer than in warm weather.

Various expedients are resorted to for the purpose of preventing the freezing of concrete. One of the common methods is to add salt to the mixing water, which lowers its freezing point. Experiments have indicated that an amount of salt equal to 5 or 10 per cent. of the weight of the water used for mixing, or approximately 13 lb. of salt to a barrel of cement, does not lower the ultimate strength of the concrete, although the time of setting is increased and the strength for short periods is decreased. Taylor and Thompson, "Concrete, Plain and Reinforced," recommend 2 lb. of salt per bag of cement, or 8 lb. per barrel. Concrete thus formed will set where the temperature is several degrees below the freezing point.

RATE OF PROGRESS

The rate of progress is usually governed by the rate of excavation, the number of forms available, the permissible length of open trench, and other factors, rather than by the rapidity with which concrete can be mixed and placed. For instance, if it be required to keep centers in place for 3 days, forms for 4 days' work must be provided if concrete is to be placed each day. Unless the total length of sewer to be built is considerable, the cost of providing sufficient forms to allow rapid daily progress may not be justified. Similarly, where the sewer is built in several operations, invert, side walls and arch separately, the concreting must be carried on in the same section of trench for upward of a week. If a high rate of daily progress is desired a very long and possibly prohibitive opening of the trench may be necessary. In such cases it will often prove more practicable to open the trench at two or more points than to attempt a high rate of progress at one opening.

In the construction of a 3-ft. sewer at Louisville, in one operation (see Chapter XV, "Forms and Centers"), 94 ft. 6 in. of inside forms, and 48 ft. of outside forms were found to be serviceable for about 1500 ft., and cost $180.84. These allowed a progress of about 48 ft. per day. As the sewer was only 1500 ft. long, a greater number of forms would have resulted in a waste of material and the discarding of forms before they were used up.

Sewers 36 in. in diameter have been built at rates of 100 to 130 ft. per day. Under average conditions, however, the rate of progress is more likely to be from 25 to 50 ft. per day. In the case of large sewers the rate at which concrete can be mixed and placed is a factor of more importance, although even upon such work the rate of progress usually depends more upon the rate of excavation than on concreting. At Louisville, Section B of the Southern Outfall (15 ft. 2 in. by 15 ft. 6 in.) required 2.99 cu. yd. of concrete per foot and 33 ft. required approximately 100 cu. yd. of concrete, an amount which might be difficult to mix and place in 1 day in congested quarters or where there were transportation difficulties. Such large sewers are constructed in several operations, the invert, side walls and arches being constructed separately and involving delays in preparing for the different portions. The usual progress on large sewers may be from 20 to 30 ft. per day. If, however, rainy days, delays owing to inefficient organization and other lost time are included, or if the average progress is computed upon the length of time from the beginning of the work until its completion, the daily progress may be much less than that shown by the above figures.

COST OF SEWERS

The cost of building concrete sewers varies greatly, being largely dependent upon the size of the structure and local conditions. The following estimate of cost is given merely as an illustration of the method of computation and to give a rough idea of cost of such work. The sewer is assumed to be 48 in. in diameter. Under these circumstances the following may be obtained: 9 men, including foremen, will mix and place about 12 cu. yd. of concrete per 10-hour day; 12 yd. of 1 : 2 : 4 concrete will contain (see Table 59) 18.85 bbl. of cement, 5.28 cu. yd. sand and 10.06 cu. yd. stone. The cost of this concrete in place will be about as follows:

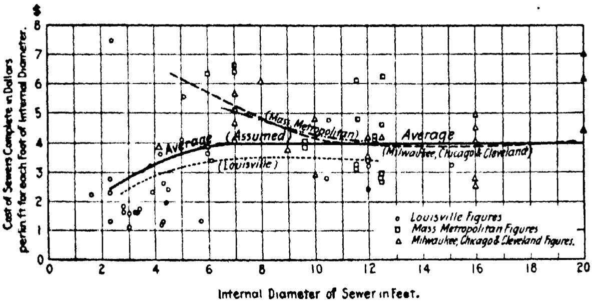


FIG 134.—Cost per foot of internal diameter of 1 lin. ft. of sewer.

Labor, 8 days at $2.00	$16.00
Labor, 1 day at $3.00	3.00
Cement, 18.85 bbl. at $1.80	33.93
Sand, 5.28 cu. yd. at $1.00	5.28
Stone, 10.06 cu. yd. at $1.00	10.06
Forms (incl. moving)	12.00
	80.27
Organization, tools, water, etc., 15 per cent.	12.04
	$92.31

Including contractor's profit, say $8.75 per cubic yard

If reinforcement is used the cost will be enhanced to the extent of 3 or 4 cents per pound of steel or from $1.50 to $2 per cubic yard in addition. On large work the cost of forms is less per cubic yard of concrete, as is also the cost of placing. At Louisville, Ky., the prices for concrete on 60 contracts for sewers ranging in size from 15 ft. 2 in. by 15 ft. 6 in. to 24 in. were from $6 to $12 per cubic yard.

In the consideration of large projects it is often desirable to obtain an estimate of a general character as to the cost of long lines or a general system of sewers. In Fig. 134 are plotted the costs of sewers at various places in dollars per foot of diameter. No distinction is made between concrete and brick and many of the examples are composed of brick with concrete foundations. The Louisville figures refer, however, to concrete and reinforced concrete only, while many of the Chicago examples are of brick.

CHAPTER XV

PROFILES, TEMPLATES, FORMS AND CENTERS

Forms of some kind are needed in constructing masonry sewers whether built of brick, stone, molded blocks or monolithic concrete. The invert must be laid accurately to line and grade and must have the correct shape, and the arch must be sustained from within until the key is in place and the mortar or concrete has set. The centering required to support the arch is usually made up in sections composed of one, two or more longitudinal parts and each length of 8 or 10 ft. is called a "center." "Profiles" are thin strips of wood the shape of the sewer, provided with nails so spaced that lines tightly drawn from one of them to similarly spaced nails in another profile or driven into the joints of a completed section of the sewer will give the required lines to which the brick should be laid. Profiles are used for laying brick, stone or block inverts. When sewers are built of concrete, molds are required to hold the semi-fluid mass in correct position until it has set, so that the structure may have the desired shape and thickness. Among such forms may be mentioned centers, outside jackets and side wall molds, which are collectively as well as individually called "forms." "Templates" are thin strips used as guides in laying brick or stone masonry or for shaping and screeding concrete.

Forms may be made of wood, of wood covered with sheet metal, entirely of metal or of metal and wood, *e.g.*, centers with steel ribs covered with wooden lagging, or wooden ribs covered with sheet metal.

It is very important that sewers be built true to the shapes and sizes called for in the design, and for reasons given in detail in Volume I it is necessary that the inner surfaces be as smooth as possible. To accomplish these results, care should be taken in laying out the forms to use the correct dimensions, and the forms should be so constructed as to be strong enough to withstand all operations incidental to placing the masonry of which the sewer is to be built and to assure a smooth finish on the inner surface of the sewer.

CENTERS AND PROFILES FOR BRICK, STONE AND BLOCK SEWERS

When sewers are to be constructed of brick, stone or molded blocks, profiles are used to aid the masons in laying the brick of the invert to correct grade and line. A profile should be made as light as possible and at the same time strong and rigid enough to always hold its true shape. As shown in Fig. 135, nails are driven in the profile, properly spaced for the several courses. The mason lays the brick or blocks to a cord tightly stretched from nails driven in the joints of the work behind to the nails in the profile ahead, corresponding to the same courses. Upon large work and where skilled masons are employed, two or sometimes three or more courses of brick may be laid to one stretching of the line. This is especially true upon relatively flat inverts, as those of horseshoe-shaped sewers. Profiles should extend high enough to enable the mason to carry the invert one or two courses above the springing line to allow room for the centers to fall after being "struck." Two profiles are usually spaced 16 ft. apart when a new invert is begun, and thereafter one profile only is used and it is generally placed about 16 ft. ahead of the finished work, a longer spacing being unwise because of the danger that the line may sag between the nails.

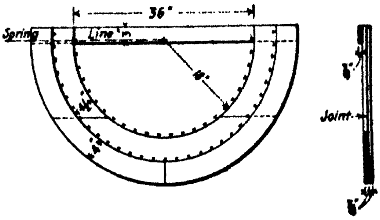


Fig 135.—Profile for 36-in. brick sewer.

The dimensions and method of constructing a profile suitable for use in building a two-ring brick sewer 36 in. in diameter, are shown in Fig. 135. Such a profile should be made preferably of clear soft stock, such as white pine, planed on both sides and of uniform thickness. Provision should be made for the mortar joint between the outer and inner rings and the nails should be so spaced as to allow for joints of proper thickness between courses. It is generally well to send the profile from the shop without having the line nails driven, so that the mason may space them to conform to the thickness of the brick actually being used. The profile represented in Fig. 135 is designed for brick 4 in. in width and 2 in. in thickness.

A profile may be secured in place by two vertical boards nailed to its sides and to a trench brace or other support above, and should be accurately set to line and grade and carefully leveled before any brick are laid.

Arch forms or centers, generally built of wood, are usually 8 or 10 ft. in length. It is common practice to build them in one piece, although some prefer to have them in two or more segments to facilitate handling, especially inside the completed sewer. They are set on chairs or legs and can be adjusted to the proper height by means of wedges. After the arch has been completed and the forms have been in place the required length of time, the centers are struck by loosening the wedges. It will be found convenient to have enough centers for a full day's work, the length required varying greatly, but commonly ranging from 24 to 48 ft. Arches turned one day may generally have centering removed the next morning; in fact, centers are sometimes struck without apparent injury to the work as soon as the masonry is completed and backfilled to a depth of 1 or 2 ft. above the crown. Centers are usually set as soon as the inverts are completed.

The size of the lagging and thickness and spacing of the ribs are governed by the size of the sewer. Centers should be made as light as possible to make them easy to handle, but they must be strong and rigid enough to receive and support the masonry without deformation.

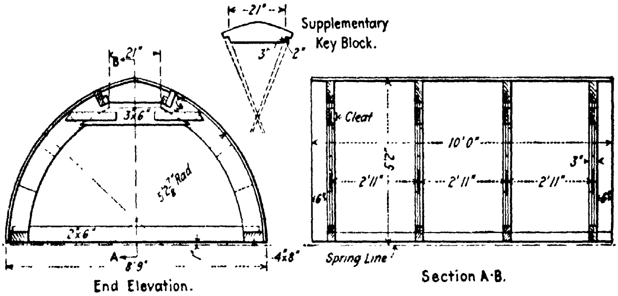


Fig. 136.—Details of block center

When sewers are constructed in tunnel, block centers are more convenient than full centers, although the latter may be used if very short, say 3 or 4 ft. in length. A block center is shown in detail in Fig. 136, and derives its name from the key block. The two large segments are first set in position and through the space at the top between them the brick and mortar are passed to the masons, after which, as the work progresses, the short key blocks are placed and the arch is completed.

WOODEN FORMS FOR CONCRETE SEWERS

Forms and centers for concrete sewers differ from those required for brick, stone or block sewers in that they should have smooth surfaces and be practically water-tight. In selecting the type to be used and the material of which it is to be built, the chief considerations are lightness and economy, as substantially the same character of workmanship can be secured with the several types and materials provided the forms are properly built and maintained. The first cost, cost of handling, *i.e.*, placing, striking or collapsing, and pulling ahead, and cost of upkeep, are some of the essentials governing the selection.

Of the three types of forms in general use at the present time—wooden forms, wooden forms covered with metal, and steel forms—it is not possible to state arbitrarily which is the most economical to use as this depends largely upon local conditions. The design of forms which can be economically and conveniently erected, struck and moved ahead under the varying conditions encountered in the construction of sewers, especially in deep trenches, has taxed the ingenuity of many experienced sewer builders.

The life of wooden forms is comparatively short. In many instances after being used eight or ten times they have to be practically rebuilt, although many times the ribs can be used again, the lagging only being renewed. When new and nicely built, wooden forms give a smooth and satisfactory finish, but after repeated use, patching and repatching, they become so rough that the interior surface of the concrete is likely to be rough and unsatisfactory.

The diversity of types of forms used upon this class of work is illustrated by a number of drawings of forms used upon the construction of the new sewerage system in Louisville, 1907-1912, with which work one of the authors was intimately associated as consulting engineer, J. B. F. Breed having been the chief engineer.

Forms for Sewer 10 ft. 7 in. by 10 ft. 1-1/2 in.—Fig. 137 gives the principal dimensions of the forms used by the Ferro Concrete Construction Co. of Cincinnati, in the construction of a horseshoe-shaped sewer 10 ft. 7 in. by 10 ft. 1-1/2 in., at Louisville, Ky., 1909.

This sewer was built in four operations. The invert concrete was placed first, then the brick paving laid, after which the side wall concrete was poured, and after this had set the concrete of the arch was placed. Usually invert concrete placed on one day had set sufficiently so that the brick lining could be laid the following day. The laying of the brick usually consumed a full day, the side wall forms were placed in position and the concrete poured the following day, and the forms allowed to remain 2 days for the setting of the concrete, after which the centers were set and the arch concrete poured and usually completed the same day. The centers were left in place 4 days to provide for the setting of the concrete. In this way 36 ft. of the sewer were built in 6 days, or an average of 6 ft. per day.

The concrete of the invert was laid continuously from the end of the old work to a bulkhead placed 36 ft. ahead and was roughly screeded to overhead wooden templets. Before beginning the pouring of the concrete, bench wall forms were so placed on each side and supported from the trench bracing that the concrete of the side wall could be poured to a

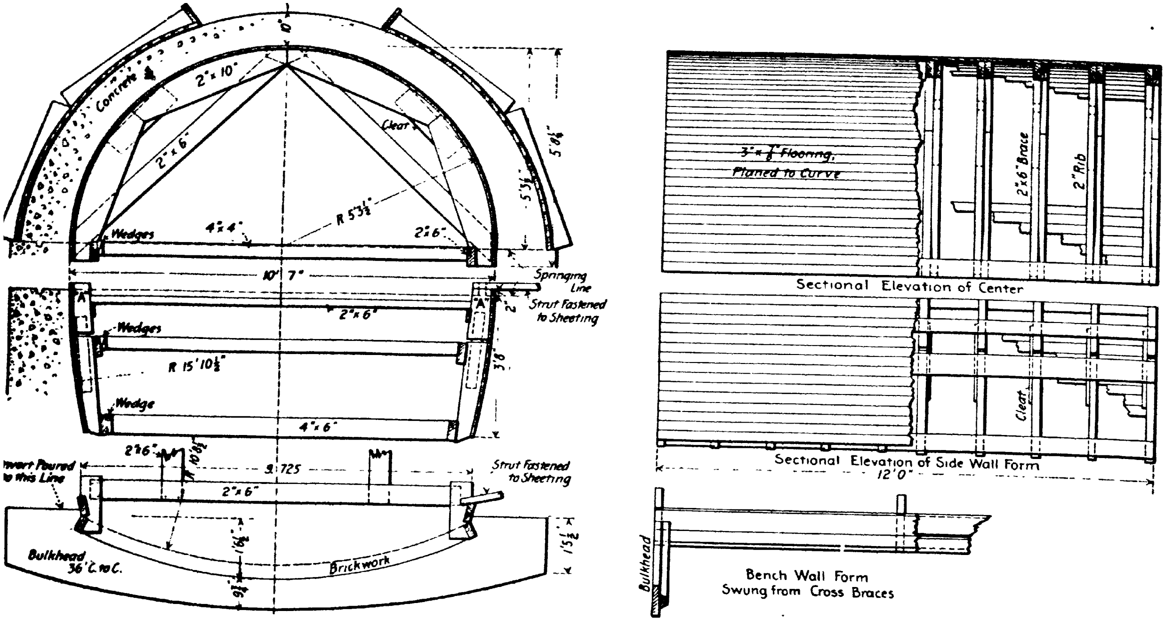


FIG. 137.—Wooden forms for large concrete sewer, Louisville, Ky.

height of about 2-1/2 in. above the invert line, thus forming a projection against which the side wall forms could be braced. After the concrete of the invert and bench walls had set, the bench wall forms were removed and the brick invert laid. The side wall forms were then placed directly upon the brick invert and braced into position against the bench wall concrete, and securely stayed against the trench sheeting. After the side wall concrete had set, the upper portions of the side wall forms, *A*, Fig. 137, was removed and the centers so set that they projected below the side walls about 6 in. The centers were wedged and supported from the lower portions of the sidewall forms.

The centers were made in two pieces cut through the crown and were fastened together either by allowing the ribs to project and nailing through them or by placing headers across the ribs and fastening the two abutting headers together. (See Fig. 139.)

The concrete of the invert and side walls was carried to the sheeting, which was left in the trench. The outside jackets were in sections 12 ft. long and 3 ft. 6 in. wide, and placed as shown on Fig. 137.

The forms were built throughout of yellow pine lumber, the side wall forms and centers being lagged with tongued and grooved flooring. The outside forms or jackets were lagged with square-edged boards.

Forms for Sewer 13 Ft. 6 In. by 13 Ft. 3 In.—The forms used in 1909 by The Weber Co., of Chicago, in the construction of a reinforced concrete sewer 13 ft. 6 in. by 13 ft. 3 in. in Louisville, Ky., are shown in Fig. 138. This sewer was built in three operations, the invert including the bench wall being first placed and screeded to templates, then the side walls were poured, and finally the arch concrete was placed.

This sewer was built in sections 20 ft. in length at first, but later the length of sections was increased to 50 ft. The invert concrete was placed and finished in a single day. The side wall forms were placed and the side walls built during the second day, the side wall forms being kept in place 2 days after the concrete had been poured, to provide for the setting of the concrete, after which the centers were placed and the concrete of the arch poured in a single day. It thus required 5 days to complete the construction of a section from 20 to 50 ft. in length. The centers were in general allowed to remain in place 7 days to afford time for the setting of the concrete, although during the warm portion of the year this time was somewhat reduced.

The invert was placed continuously from the end of the completed work to the end of the section under construction, a bulkhead being provided at this point to hold the concrete in position. This bulkhead, with key strip and notches to provide for projecting longitudinal steel reinforcing bars, is shown in Fig. 138.

Bench wall forms, constructed as shown in Fig. 138, were placed in position and securely fastened before the concrete of the invert was

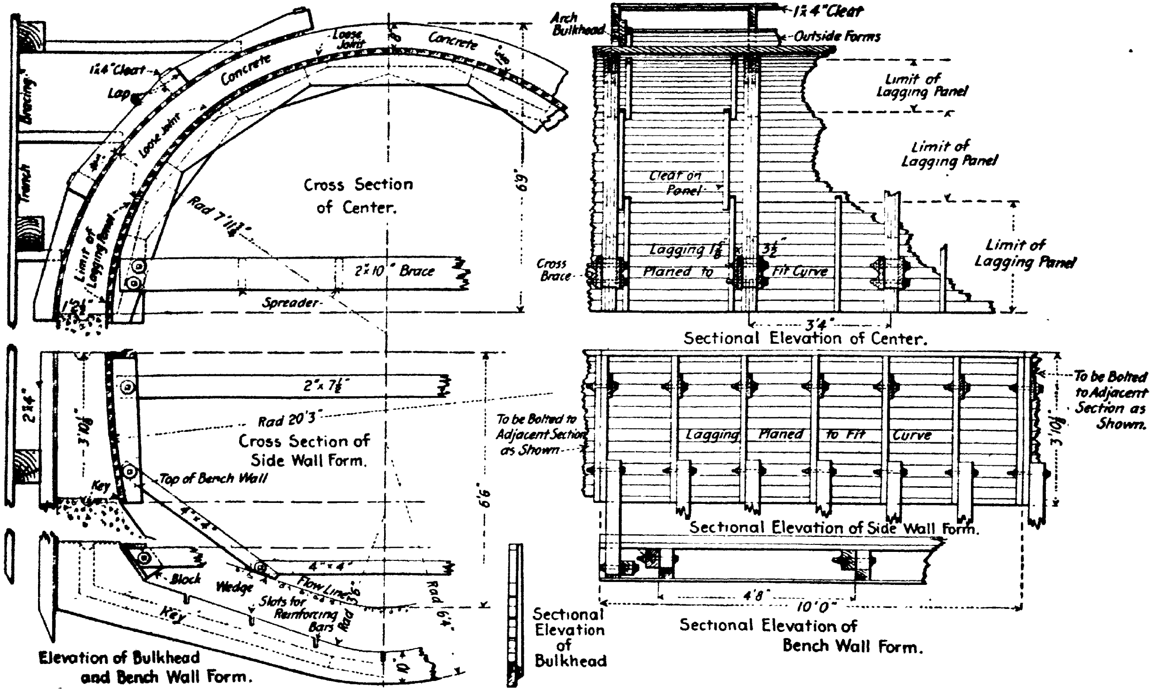


FIG. 138.—Details of wooden forms for horseshoe sewer, Louisville, Ky.

FIG 139.—Wooden centers for large concrete sewers, Louisville, Ky

FIG. 140.—Outside forms or jackets covering fresh concrete, Louisville, Ky.

(Facing page 402)

placed. Usually the concrete on the sides of the invert was mixed somewhat drier than that in the center so that the weight of the bench wall concrete did not force the invert concrete out of position. In some cases, however, the invert concrete was first placed the entire length of the section, after which the bench wall concrete was placed, the time intervening being sufficient to provide for the partial setting of the invert concrete. After the concrete of the bench walls had set, the bench wall forms were removed and the side wall forms placed in position and braced against the completed bench walls.

After the concrete of the side wall had set, the ribs for the centers were placed in position and supported on the side wall forms. These ribs were made up in full sections, as shown by the drawing, and were carried forward without difficulty through the completed sewer under the centering in place. After the ribs had been placed in position the panels of lagging, which were about 2-1/2 ft. in width, were placed upon the ribs and nailed to them sufficiently to hold them in place. There were seven of these panels for each complete center 10 ft. in length.

In some places upon this work the trench was so wide that to have entirely filled the space between the side wall forms and the trench sheeting would have required a large unnecessary quantity of concrete. At such places 2 × 4-in. strips were driven into the ground, braced against the sheeting and sheathed on the side next the sewer with 3/4-in. boards, thus providing an outside form to hold the concrete in its proper place and restrict its dimensions in conformity with the requirements. Above the top of the side wall, outside jackets were used for this purpose. These jackets, Fig. 138, were in sections about 3 ft. wide and 10 ft. long and were placed in position as the concrete of the arch was brought up around the centers. Similar jackets are shown in Fig. 140.

In this instance, as is usually the case, the jackets or outside forms did not come clear to the top of the arch, as the slope near the top was so slight that there was no difficulty in holding the concrete in proper position without forms. While this is common and good practice, care should be taken to avoid the placing of an unnecessary surplus of concrete along the top of the sewer, which may be caused by leaving the opening between the jackets too wide, and by lack of care in rounding off the concrete.

METAL-COVERED WOODEN FORMS FOR CONCRETE SEWERS

A sheet metal covering over wooden forms assures to the concrete a smooth finish and also prolongs the life of the forms. It is difficult to make the metal fit perfectly over the forms, and sometimes it is so thin and fits so loosely that it gives to the finished concrete surface a wavy appearance. Where the metal is of suitable thickness, No. 18

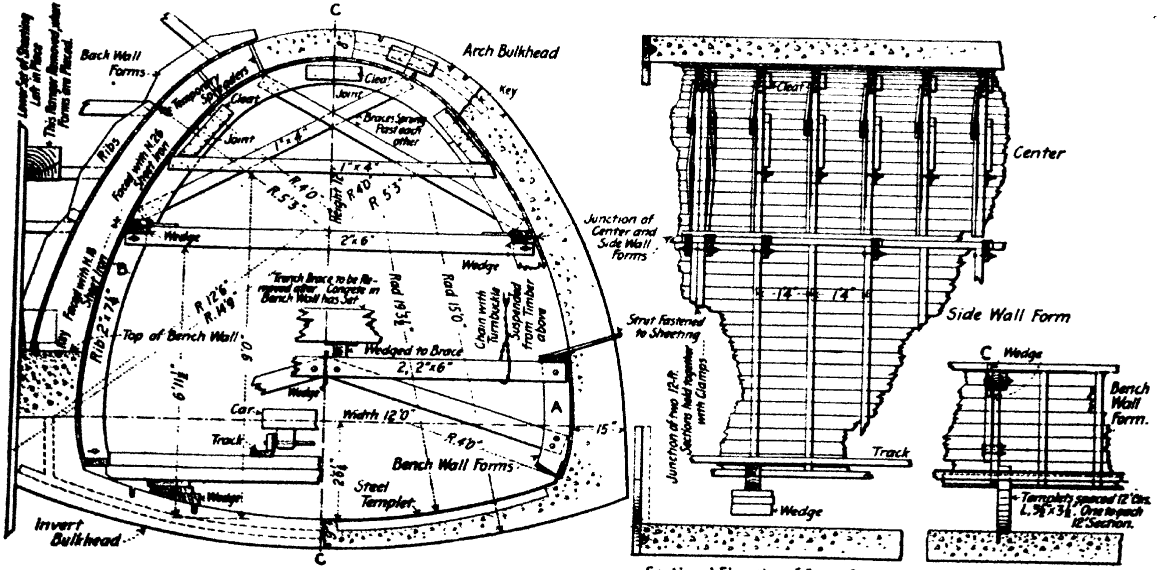
or No. 20 gage (0.05 in. or 0.0375 in. in thickness, 2 lb. or 1.5 lb. per square foot), well stretched and thoroughly fastened, this unevenness is not usually sufficient to constitute a serious defect.

The finish obtained by using metal-covered forms is scarcely better than that obtained at first by the use of well-made wooden forms, but after the latter have been used several times the lagging becomes frayed and broken, after which the concrete surfaces are likely to be rough and have a finish much inferior to that obtained with metal-covered forms.

The difference between the first cost of wooden forms and wooden forms covered with metal is due principally to the extra cost of the metal, the labor required for attaching it not being much greater than that required to dress and perfect the surface of the wooden forms, which cost is saved if the forms are covered. The cost of handling metal-covered forms is about the same as that of handling wooden forms, while the cost of upkeep is generally much less, as the wear upon the wooden lagging, which necessitates its early renewal, is avoided. There appears on the whole to be little difference between the ultimate cost of the wooden and the metal-covered forms, although if the sewer to be constructed is long enough to require the use of the forms more than eight or ten times it is likely that the metal-covered forms will prove somewhat less expensive. Even with this type of forms, continued use generally results in more or less breakage or deformation, necessitating repairs. Where the sewer is very long and the work is prosecuted progressively from one end to the other, requiring the use of the forms many times, it is probable that steel forms will be found to give more satisfactory results at less cost than wooden or metal-covered forms. On the other hand, it is believed, at least by some practical sewer builders, that wooden forms are much more economical than steel forms for short sewers, say sections up to 1000 ft. in length.

Forms for Sewer 12 Ft. by 12 Ft.—The forms used in the construction of a 12 × 12-ft. semi-elliptical reinforced concrete sewer at Louisville, Ky., by C. T. McCracken & Co., Columbus, Ohio, 1909, are illustrated in Fig. 141. It was first intended to build this sewer in three operations—invert, side walls and arch—and the forms were built with that method in prospect. It was later decided to build the invert and bench walls to the height shown on the drawing in one operation, after which the arch was to be poured. The supplementary bench wall form, *A*, Fig. 141, was therefore provided, but, as the lower portion of the arch form, *B*, had already been constructed, it was used throughout the work although had the original intention been to pour the concrete in two operations, this portion of the form would not have extended more than 2 to 4 in. below the top of the bench wall.

The bench wall forms with the angle iron templates attached were first placed in correct position as to line and grade, the forms being hung


C
Arch Bulkhead
Key
Back Wall Forms
Lower Set of Sheeting Left in Place
This Ranger Removed when Forms are Placed.
Ribs
Faced with N.26 Sheet Iron
Temporary Spreaders
Cleat
Joint
Braces Spring Past each other
1"x 4"
R.4'0"
R.5'3"
Height 12'
R 5'3"
Wedge
2"x 6"
Rad 19'3½"
Rad 15'0"
Chain with Turnbuckle
Suspended from Timber above
Junction of Center and Side Wall Forms
"Trench Brace to be Removed after Concrete in Bench Wall has Set"
R.12'6"
R.14'9"
Faced with N.18 Sheet Iron
Rib 2"x 7½"
Key
Top of Bench Wall
9.0
6'11½"
Wedged to Brace
2, 2"x 6"
Strut Fastened to Sheeting
Car
Width 12'0"
A
15"
Track
R.4'0"
Bench Wall Forms
2'6"
Steel Templet
Invert Bulkhead
Cleat
Center
14"
Side Wall Form
Junction of two 12-ft. Sections held together with Clamps
Track
Wedge
C Wedge
Bench Wall Form.
Templets spaced 12' Ctrs. L.3⅝"x 3½". One to each 12' Section.

Cross Section.

Sectional Elevation of Center, Side Wall Form and Invert Bulkhead.

Elevation of Bench Wall Form.

Vertical Section C-C.

FIG. 141.—Details of wooden forms covered with sheet iron for semi-elliptical sewer, Louisville, Ky.

from the trench braces above by means of chains and turnbuckles and braced from the sheeting. The concrete was laid continuously, and as there were no bulkheads used, except at the end of the day's work, upon which the longitudinal reinforcing bars could be supported, these bars were placed upon small concrete blocks molded and placed in proper position upon the ground. The transverse bars for the side walls were held in place by notched scantlings, to which they were wired, which were removed before the concrete was poured to the height of them. The notches shown in the invert bulkhead, Fig. 141, were cut to allow the longitudinal rods to pass through the bulkhead required at the end of the day's work. As fast as the invert concrete was placed, screeded and floated, the angle iron templates were removed and when this concrete had set hard enough to prevent its being forced out of place by fluid concrete placed upon it, the bench walls were poured.

After the invert and bench wall concrete had set, the forms were removed, the lowest two trench braces were taken out and the arch forms were set in proper position. These forms were carried down to and supported by blocking resting upon the finished invert. The arch forms were in three pieces as shown in Fig. 141. The bolt holes in the braces, used to hold the lower portions of the arch forms in correct position, and the holes in the end ribs of these forms, were slotted so that the forms could be readily adjusted to slight irregularities in the concrete bench wall against which they were placed.

The braces holding the bench wall forms in place were attached to them by bolts, so that they could be easily removed and the forms and braces carried ahead. The centers were dropped by knocking out the wedges between the bottom supporting timbers and the invert. The top braces were then taken off the lower portions of the centers, and the latter placed on a car, after which the top piece was lowered to the car and the whole pushed ahead under the centers still in place supporting fresh concrete.

The outside forms were in panels of convenient size for handling, and were placed in position from time to time as the concrete was carried up around the centers. They were supported temporarily by wooden struts or spreaders, wedged against the centers, which struts were taken out before the concrete reached them, and by braces driven against the sheeting, the latter remaining until after the concrete had set.

The forms were lagged with 7/8-in. tongued-and-grooved flooring 4 in. wide. The bench wall forms and lower portions of the centers were covered with No. 18 sheet iron, and the upper portion of the centers with stove pipe iron.

The sewer was built in sections 48 ft. long. The invert and bench walls were poured in a single day, and the bench wall forms were allowed to remain in place 2 days after the concrete had been placed. The arch forms were set and the concrete poured on the next day. Thus a single section of sewer, 48 ft. in length, was built in 4 days, making the average progress 12 ft. per day. The arch forms, before being struck, were allowed to remain in place 5 days after the concrete had been placed.

STEEL FORMS FOR CONCRETE SEWERS

There are several types of patented steel forms which usually are obtained on a rental basis, generally at a price fixed per foot of forms rented. In estimating the cost of using such forms, it should be borne in mind that the lessee is required to pay the cost of unloading and loading the forms and hauling them from the cars to the work and from the work back to the cars at the end of the job.

The finish of concrete poured against good steel forms is usually excellent, although at times, especially in cold weather, there is a tendency toward "peeling," which is more prevalent than when wooden forms are used. This "peeling," which is the adhesion of a thin layer of the concrete to the center when the latter is removed, may be caused in some instances by the cooling of the concrete next to the steel forms to such an extent as to prevent its setting within the length of time the forms are allowed to remain in place.

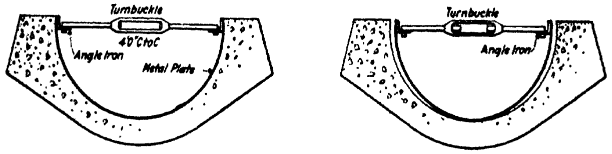
Forms for sewers from 24 to 60 in. in diameter, to be constructed either in one or two operations, may often be obtained from stock, but forms for larger sewers are constructed upon orders in most cases. Most metal forms come in sections 5 ft. in length, corresponding to the width of a single steel plate, although when in use the smaller forms are fastened together in trains by means of eyes and wooden wedges. When moving invert forms, the wedges are knocked out and the individual sections are carried forward and reset. The arch forms are moved in trains about 50 ft. long on rollers. Where special large forms are used, the individual sections are bolted together in trains varying in length, but usually about 20 ft. long, and are carried forward on carriages.

Steel forms have been extensively made by the Blaw Steel Construction Co., of Pittsburg, Pa., and others. While some of these forms have been patented, engineers and contractors also build metal forms after their own designs.

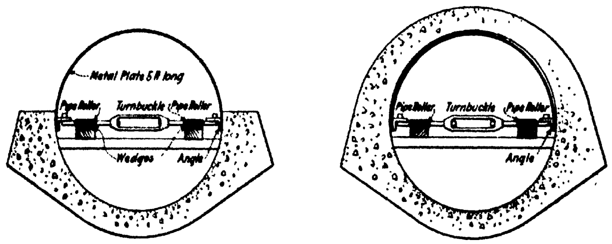
Some of the smaller steel forms have a certain amount of adjustability, amounting to from 3 to 5 in. in the diameter, so that, for example, a 48-in. half-round form may be used for building both a sewer 48 in. and one 45 in. in diameter. This is accomplished by rotating turnbuckles, thus making the forms larger or smaller as desired for the work in hand.

An example of the use of steel forms in building 2000 ft. of sewer may be helpful in estimating the cost of steel forms. In this case 150 ft. of half-round forms are assumed to have been used. The arch forms were required to remain in place 48 hours and the custom was to remove the invert forms in 24 hours so that 50 ft. of forms were used for invert, which was placed each day, and 100 ft. of forms for arch, which was placed once in two days. The charge for 150 ft. of forms 36 in. in diameter, based upon the quotations given in Table 70, would be $225 f.o.b. cars in the city in which the work was to be done, equivalent to a cost of 11-1/4 cents per foot for the 2000 ft. of sewer constructed.

If the length of sewer to be built had been but 1000 ft., the cost given in the foregoing illustration would be increased to 22-1/2 cents per foot, provided 150 ft. of forms were leased. Where the length of sewer to be built is less than 1000 ft. manufacturers state that from 60 to 100 ft. of forms are generally used with a corresponding decrease in their total cost. If, on the other hand, a longer sewer is to be built, and the desired rate of progress is such that the length of forms used need not be more than 150 or 200 ft., the cost for forms per linear foot of sewer may be greatly reduced. In such cases, the lengths of forms required will depend upon the required rate of progress and the length of trench which may be kept open ahead of the placing of the concrete.



Invert Forms in Place. Invert Forms Released.



Arch Forms in Place. Arch Forms Released.

Fig. 142.—Steel invert and arch forms.

If a given piece of work requires the construction of two sewers,

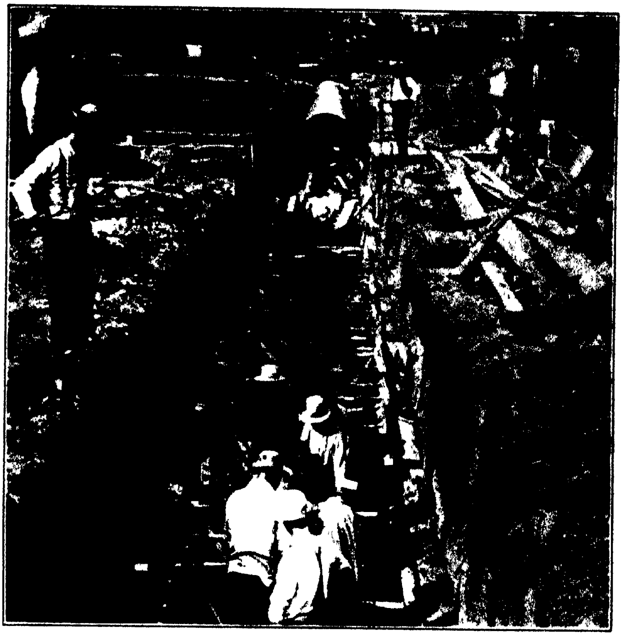


FIG. 143.—Releasing half-round Blaw invert forms preparatory to moving them ahead

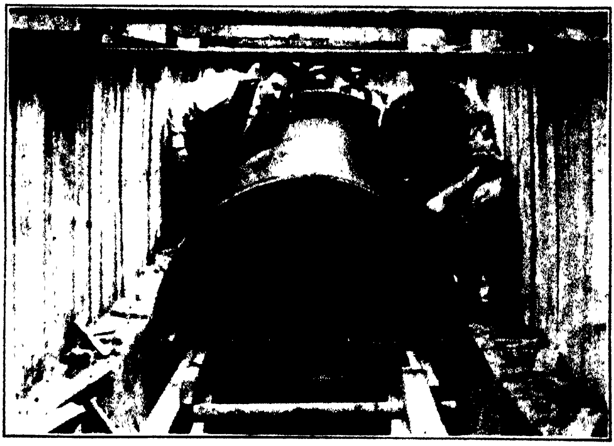


FIG. 144.—Train of small steel forms after being rolled ahead.

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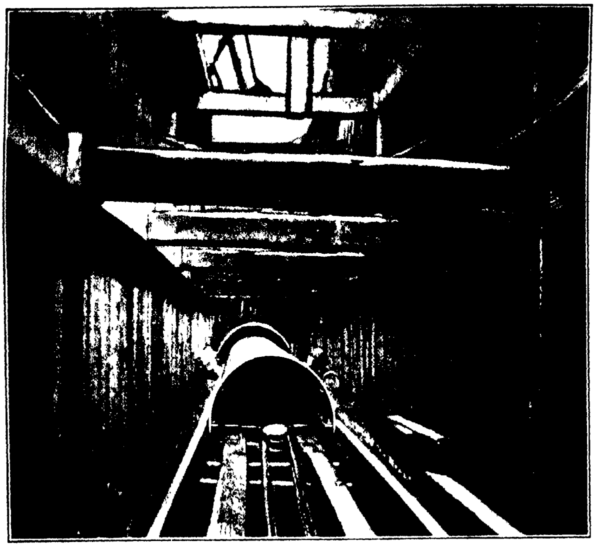


FIG 145.—Pulling 100 feet of Blaw steel forms through finished 5-foot conduit

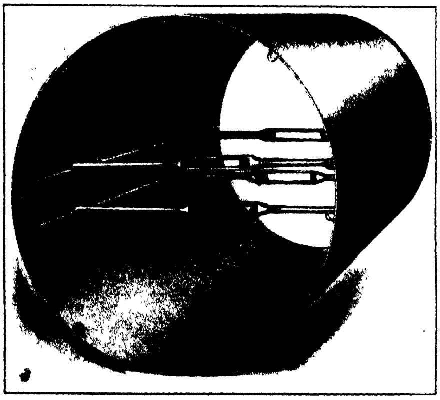


FIG. 146.—Full round Blaw form with tie rods, angle iron stiffeners and U lugs.

differing in diameter but about 3 in., as for example, a 33-in. and a 36-in. sewer, a single set of forms is usually provided, the difference in size being obtained by an adjustment of the turnbuckles. Such forms for invert and arch are shown in Fig. 142, in position to receive concrete and after being released and ready to be moved forward. The tie rod and turnbuckle, by means of which the centers are extended and drawn in, are also shown, as well as the rollers by means of which the centers are moved by rolling them along stringers supported upon cross braces.

Fig. 143 shows a number of sections of 72-in. half-round Blaw forms in a trench, just released after being used for invert construction.

Fig. 144 shows a train of Blaw forms fastened together and after being moved forward on rollers. If centers are to be moved in this way they can only be moved after the concrete has set, which limits the frequency of placing concrete to the period during which the centers must be left in place. If, therefore, the train of centers is limited to 50 ft., and the centers are required to be left in place 4 days, the average progress of the arch cannot exceed 10 ft. per day. Greater progress will require the use of a greater length of centers, which should be broken up into train lengths of about 50 ft., for economical handling, one train after another being moved ahead.

When half round steel forms are used for building invert, they are usually hung from the trench timbers by chains spaced every 5 or 8 ft. By having small turnbuckles in these hangers, the forms can be adjusted to the proper grade in a very short time. After the forms are in place, they should be braced at the sides to prevent any sway, and also a vertical brace should be placed at every other section to prevent the forms from rising while the concrete is being placed. After the invert forms have been in place the required time, they are either turned over and used for the arch, or are pulled ahead and used for another invert. On the Louisville sewers, where the arch forms were required to be in place 4 days and the invert forms 2 days, usually 100 ft. of arch forms and 50 ft. of invert forms were used. After the invert forms have been removed, timbers are placed across the invert at intervals of 6 or 8 ft., on which are laid longitudinal timbers. These are used to support the centers and as rails on which to roll the arch forms ahead as in Fig. 145. By means of a windlass and block and tackle, six men can pull ahead 100 ft. of arch forms in trains of 50 ft. and place them ready for concrete in about 3 hours.

When the small semicircular forms used for building inverts are moved they are generally dragged along the completed invert, without the use of rollers. The manner of assembling small steel forms is well illustrated by Fig. 146, which shows the angle irons to which the tie rods are attached, the tie rods and turnbuckles, and the lugs provided for fastening together the adjacent sections. This figure also shows the manner of constructing a complete cylindrical form. The angle irons placed on either side of the upper half are slotted so that they will fit down over U lugs in the bottom half. After the upper and lower halves are brought together in this manner, wedges are driven through the U lugs, thus holding the two parts securely in place. The turnbuckles are then taken up to bring the form to the correct dimensions.

Forms for Sewer 15 Ft. 6 In. by 15 Ft. 2 In.—The details of the construction of steel forms used by Chas. F. Fitch, of Louisville, Ky., subcontractor for masonry upon the construction of Section B of the Southern Outfall in Louisville, Ky., 1909, are shown in Fig. 147.

This sewer was built in three operations, invert, side walls and arch. The invert and bench wall concrete was usually placed in a single day. The following day the side wall forms were placed and the concrete poured, after which the side wall forms were required to be left in place 2 days. The arch forms were then placed and the concrete poured, which was usually done in a single day, after which the centers were required to be left in place 7 days before being removed. The minimum length of time required for the completion of a section of this sewer, which varied in length from 30 to 60 ft., was, therefore, 5 days or an average progress of from 6 to 12 ft. per day. Greater progress was in fact made by working at several openings, which is common practice upon work of this size. It was usual upon this work, as upon the construction of most of the other large sewers in Louisville, to lay the invert as soon as the trench was excavated to grade, and it frequently happened that several sections of invert and sometimes more than a single section of side walls were placed before the later operations were begun.

The forms used upon this section are shown in Fig. 147. The bench wall forms were similar to those used upon other work and were constructed of wood. The side wall forms were constructed of steel and were removed before the centers were placed. The centers at first used were built of steel and were not collapsible. They were braced by means of struts, as shown in the drawing, and moved forward in trains about 20 ft. in length. Later it was deemed advisable to rebuild the centers and make them collapsible. This was done by cutting the channels and plates at the crown and inserting hinges; at the same time the channels were reinforced with the stiffeners shown in the drawing, after which the diagonal and upper horizontal struts were not used. After remodeling in this way, the forms were moved ahead by lowering them, drawing them in and carrying them forward under centers in place.

Forms for Sewer 14 Ft. by 13 Ft. 8 In.—The forms used in the construction of a reinforced-concrete sewer 14 ft. by 13 ft. 8 in. in size, in

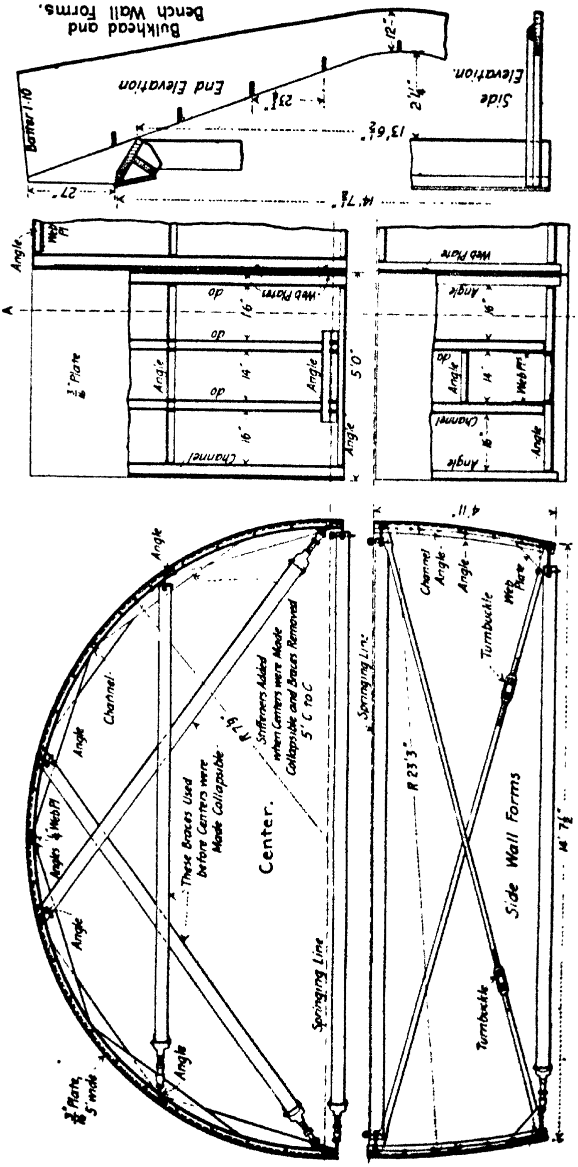


FIG. 147.—Steel forms for horseshoe sewer, Louisville, Ky

Louisville, 1909, by the American Engineering & Construction Co., of Chicago, Ill., are shown in detail in Fig. 148.

This sewer was built in three operations, the invert and bench walls being first poured, then the side walls and finally the arch. The placing and finishing of the concrete of the invert and bench walls usually consumed one day. The succeeding day the side wall forms were placed and the concrete was poured. These forms were required to be left in place 2 days after the concrete had been poured, after which the centers were placed and the arch concrete poured in a single day. The centers were required to be left in place 5 days after the pouring of the concrete. The length of time required to complete a section of sewer, which was usually about 25 ft. in length, was, therefore, 5 days, giving an average rate of progress of 5 ft. per day.

The bulkheads, bench wall forms and outside arch forms were constructed of wood. The side wall forms and the centers were constructed of steel. The centers were hinged at the crown so that they could be drawn in and moved forward through other centers in place sustaining fresh concrete. The bottom struts were removed from the centers after the concrete had been poured, so that the centers from behind could be moved forward on carriages, as shown in Fig. 148.

These carriages were equipped with jacks, Fig. 149, which could be fastened to the form ribs. After the centers had been moved to the proper location the jacks were extended until the forms were brought to the correct line and grade. Upon some of the Louisville work, the cars with attached jacks were removed after the centers had been securely braced to hold them in position. In other cases the centers were allowed to remain supported by and attached to the jacks while the concrete was being poured and until it had acquired sufficient strength to permit the removal of the centers.

Forms without Internal Bracing.—In some cases forms have been used which required no internal bracing for their support, being so rigid as to be self-supporting. Such forms were used upon a 13-1/2 × 14-ft. horseshoe shaped sewer built in Louisville, Ky., 1909, and are illustrated by Fig. 150.

Use of Steel Forms in Tunneling.—Common practice in lining tunnels with concrete is to use rings made of angle or channel iron, which are carried in and set up in place before the lagging is adjusted. The concrete is then, or may previously have been, placed in the invert. As it is brought up on the sides, strips of lagging, either of wood or of steel, are placed against the rings, thus giving access at all times to the concrete for tamping purposes. When it is necessary to close the arch at the crown, the concrete is shoveled in from the end ring and thoroughly rammed. To make this practicable it is necessary to have the rings placed fairly close together and to use short lagging. The steel rings or

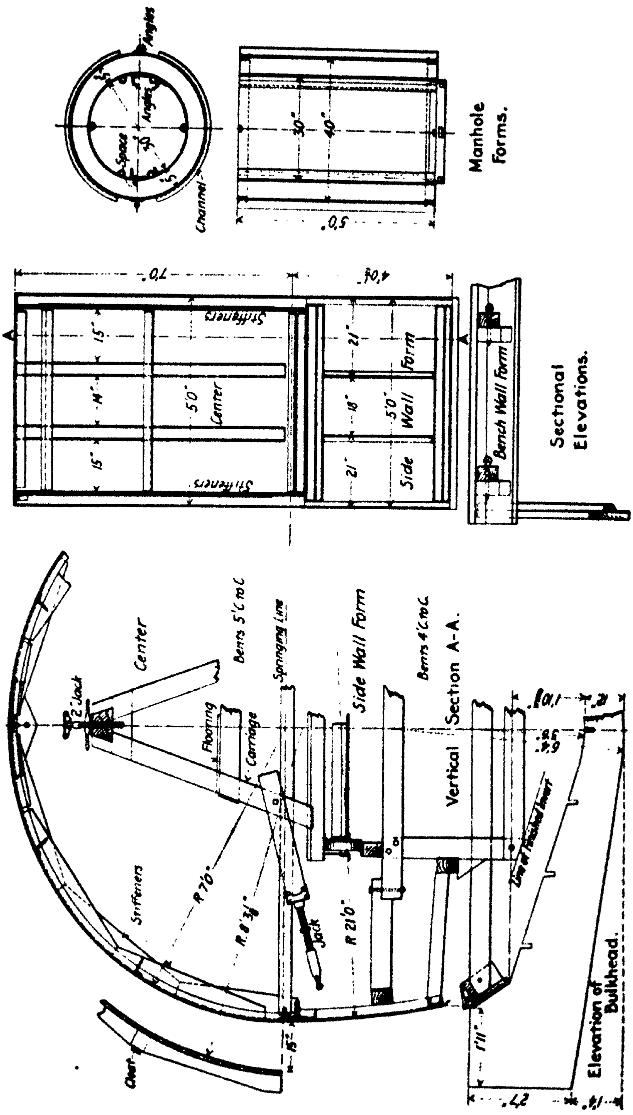


Fig. 148.—Steel forms for horseshoe sewer, Louisville, Ky.

ribs and the ribs with lagging in place, are illustrated by Figs. 151 and 152, prepared from photographs taken of 76-in. tunnel centering used upon work for the Metropolitan Water Board, Boston, Mass., by James Hanreddy, Chicago, Ill., contractor. For these photographs and several others used in this chapter the authors are indebted to the Blaw Steel Construction Co., of Pittsburg, which has made a specialty of collapsible steel forms.

FORMS FOR SEWERS BUILT OF CONCRETE AND BRICK OR BLOCKS

Many combinations of concrete and brick, stone, blocks or other materials have been used in sewer construction to meet various conditions. Sewers have been built with concrete inverts and brick arches, brick inverts and concrete arches, and both concrete and brick in both invert and arch. The most common combination is the concrete invert with brick, stone or block lining and concrete arch. Forms for sewers built of brick and concrete are similar to those used for like purposes for sewers built entirely of either one of these materials. When the invert is lined with brick, allowance must be made in building the forms for the concrete work, for the thickness of the brick and of the joint, which is usually about 1/2 in. thick, between the brick and the concrete. If allowance for this joint is neglected, it means either the cutting out of some of the concrete or the chipping of the brick in order that they may be laid to the correct line and grade.

BUILDING CONCRETE SEWERS IN ONE OR MORE OPERATIONS

Where concrete sewers are built in two or more operations there is likely to be more or less trouble in securing good joints between the horizontal sections and there is usually some finishing required because of rough concrete due to the failure of the centers to fit exactly the concrete of the invert. It has therefore been found advantageous in the construction of a number of small sewers to pour the concrete of both invert and arch at one operation, thus reducing to a minimum the cost of chipping, patching and finishing the inner concrete surface. This has been successfully done in Louisville, Ky., upon sewers ranging from 2 to 4 ft. in diameter, but it is doubtful if it will prove practicable to build much larger sewers by this method.

On small sewers where the quantity of concrete per linear foot is only a small fraction of a cubic yard, the cost of preparation for mixing and pouring concrete, such as placing mixing boards, hoppers, and chutes, which is a considerable item, is the same whether half or the whole of the

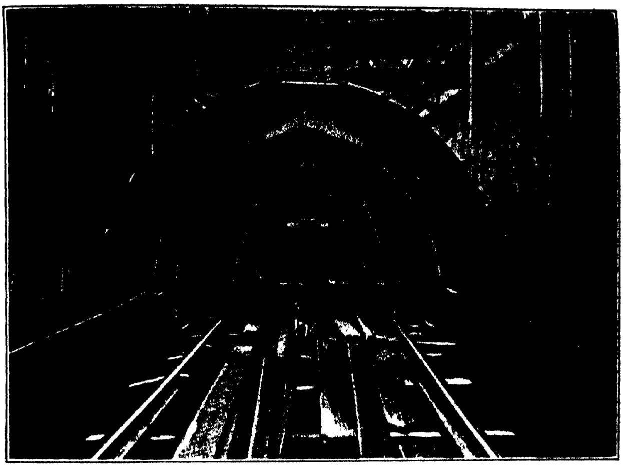


FIG. 149.—Moving collapsed Blaw centers on traveler through other centers in place

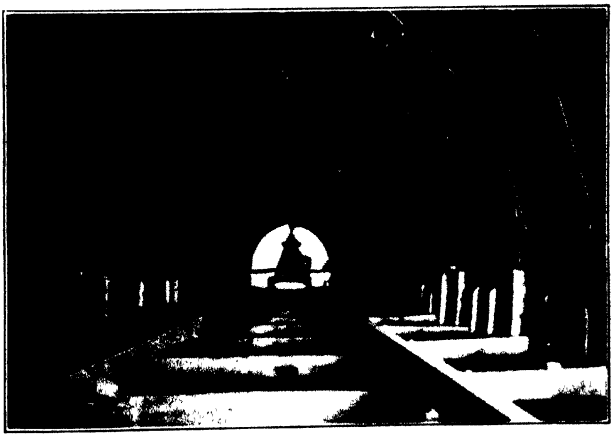


FIG. 150.—Interior of 14-foot Blaw centers without inner support or braces.

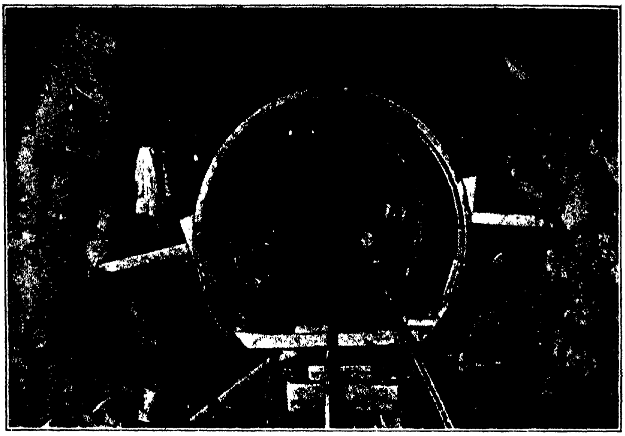


FIG. 151.—Steel ribs in position to support wooden lagging for retaining concrete in place

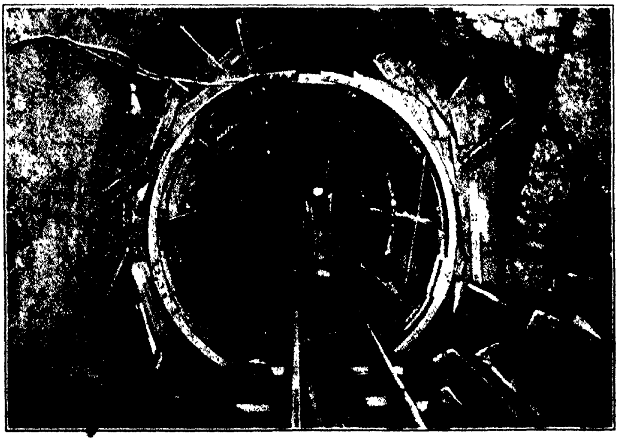


FIG. 152.—Steel ribs supporting lagging and concrete tunnel lining.

sewer is built at one time, although in the latter case the quantity of concrete placed is nearly double the quantity handled in the former. The cost of preparation per cubic yard, therefore, is only about half as much where the work is all done at one time.

By completing the sewer in one operation the length of open trench required is somewhat shorter than if the invert is first laid and allowed to set before the arch is poured.

It has also been found somewhat cheaper to handle the full round forms than the half round forms. The costs of erecting, striking, and moving forms upon five sewers of about 1000 ft. length each are given in Table 66.

TABLE 66.—COST OF ERECTING, STRIKING, AND MOVING FULL ROUND AND HALF ROUND FORMS. PER LINEAR FOOT OF SEWER BUILT

Type of forms	36 in	42 in	48 in.	54 in.
Full round wooden forms	$0 45	$0 43	$0 45	. . . .
Half round steel forms	. . .	0 70	. . . .	$0.79

It appears that the cost of handling the full round forms was only about 60 per cent. as much as the cost of handling the half round forms, assuming the cost of handling wood and steel forms to be the same, which seems to be a reasonable assumption for forms of these sizes.

When full round forms are used, they are generally supported on concrete blocks. These blocks are made about 14 in. long, the length being taken at right angles to the line of the sewer, the upper surface conforming to the inside curvature of the sewer. The depth of the block must not be less than the required thickness of the concrete of the sewer invert, and it has been found that better results can usually be obtained if it is an inch or two greater. The width of the block parallel to the axis of the sewer is about 8 in., thus allowing sufficient bearing for the forms. After the bottom of the trench has been properly graded, the blocks are set carefully to line and grade, and the forms are then placed upon them and are securely braced at the sides and top to prevent any movement while the concrete is being placed. Especial care should be taken to brace the forms down, as otherwise they may float upon the fluid concrete and be thrown out of alignment.

Full Round Wooden Forms for Building Concrete Sewers at One Operation.—Figs. 153, 154 and 155 illustrate the wooden forms designed and successfully used in 1911 by F. C. Williams, Division Engineer, Commissioners of Sewerage, Louisville, Ky., for the construction of a sewer 3 ft. in diameter and about 3000 ft. in length. This type of form has been used by him in the construction of several other sewers and has always proved economical and satisfactory in all respects. Fig. 153 shows the cylindrical forms and the outside jackets in place.

The sketch also indicates how these forms can be used for building the sewer in two operations, if for any reason that method of procedure is desirable, the concrete of the invert being shown as completed for a portion of the distance, and the bulkhead being shown in place to retain the fluid concrete of the arch.

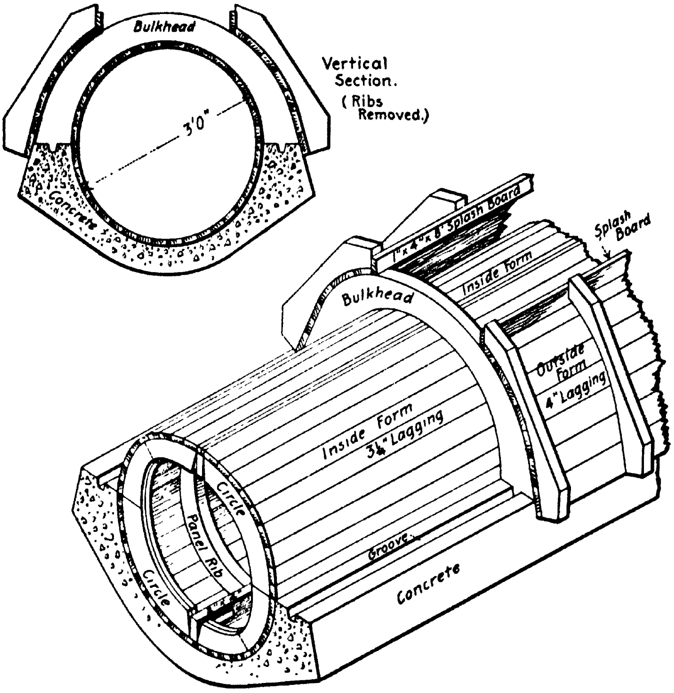
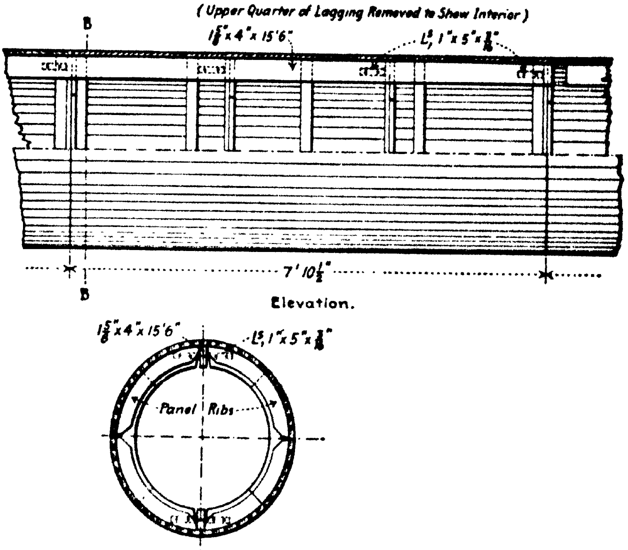


Fig. 153.—Wooden forms for building circular sewer in one or two operations, Louisville, Ky.

The inner forms are built in sections 7 ft. 10-1/2 in. long, each section consisting of four panels, shown in details *G*, *H* and *I*, Fig. 155. A skeleton support consisting of rings held together by two stringers, one at the top and one at the bottom, is first placed in position in the trench. The panels are placed upon and attached to this skeleton support as shown in Fig. 154.

When the concrete has acquired a sufficient degree of hardness, the top and bottom stringers holding the skeleton ribs in place are removed, thus allowing the ribs and panels to be collapsed and carried out through other forms supporting fresh concrete. It will be noticed that there is no internal bracing required by these forms, so that the space inside the skeleton ribs is entirely free and there is no obstruction to interfere with carrying forms through them.

For the construction of a sewer 1100 ft. in length, 94 ft. 6 in. of inside forms and 48 ft. of outside forms were provided. The dimensions, quantity of lumber and number of sawed, curved pieces required, the cost of lumber and millwork and labor entering into the building of these forms, are given in Table 67. All curved pieces were purchased cut to template at a local mill so that the waste and profit are included in the unit prices.



Elevation.

Cross Section B-B.

FIG. 154.—Full round wooden forms, Louisville, Ky.

The total cost of the forms was $180.84, the inside forms costing $1.72 and the outside forms 38 cents per linear foot. The total cost of building these forms was 16.4 cents per linear foot of sewer constructed.

This sewer required 0.22 cu. yd. of concrete per linear foot, upon which basis the first cost of forms was 74.5 cents per cubic yard of concrete. The forms were in such good condition at the end of the work that they were used for the construction of another sewer 700 ft. in length, making a total of 1800 ft. of sewer constructed with these forms. Upon this basis the cost of forms was 10 cents per foot of sewer built with them, or 45.5 cents per cubic yard of concrete. The forms at the end of the work were in such condition that they could be no longer used. In general, it is found that such forms can be used for the construction of only about 1500 ft. of sewer.

TABLE 67.—ACTUAL COST OF FULL ROUND FORMS REQUIRED FOR CONCRETE SEWER 36-IN IN DIAMETER, LOUISVILLE, KY., 1911

Name of piece	Number and dimensions of pieces	Unit cost	Cost of lumber and mill work	Cost of labor, erecting, fitting, etc	Total cost	Cost per foot of forms
		Inside forms				
Circles for skeleton forms	144 ¾ in × 23¼ in 72 –¾ in × 24¼ in 144 –¾ in × 12¼ in	$0 05	$18 00	$15 70	$33 70	$0 3566
Panels—ribs,	240-2 in × 23¼ in	0 08	19 20			
lagging	960[1] ft B M 3¼ in wide (tongue not incl in B M)	$29 per M	27 84	51 50	98 54	1 0428
Stringers	12—2 in × 4 in 15 ft —6 in	$0 24	2 88	1 30	4 18	0 0442
Angle irons	144-3/16 in × 1 in × 5 in × 5 in	0 15			21 60	0 2286
Bolts	144—½ in	$1 20 per gross			1.20	0 0127
Screws	288—1 in	$0 48 per gross			0 96	0.0102
Nails					2 30	0 0248
				Total	$162 48	$1 7194
		Outside forms				
Panels—ribs,	60 -2 in × 31 in	$0 10	6 00			
lagging	288 ft B M 1 in × 4 in	$20. per M	5 76	6 60	18 36[2]	0 3825
				Grand total	$180 84	

[1] Flooring—tongued and grooved 3¼ in flooring was sometimes used when narrower stock could not be obtained although 3¼ in strips are too wide for a 30 in. sewer

[2] For 48 ft.

Note.—There were 94 ft. 6 in. of inside and 48 ft. of outside forms built in accordance with Figs. 153, 154 and 155.

When full round wooden forms are used, they should be thoroughly water-soaked before being placed in the trench, otherwise the water in the concrete will cause them to swell and crack the sewer the whole length of the run. These cracks usually appear on each side of the arch near the top of the outside jacket. When they were first noticed at Louisville, it was thought that the key strip that is always placed along the top of the forms after they are erected, was too tight, but it was afterward proved that the lagging itself had swelled about 1/16 in., thus causing the fracture in the concrete. Wooden forms, especially when new, should be protected from the sun, otherwise they will dry out, causing the joints to open so that when the concrete is poured the thin mortar will run into and through them giving to the concrete a rough surface which must be chipped, pointed and smoothed, involving much expense and producing results which are not as satisfactory as those produced by tight forms. After being used once or twice the forms give no further trouble on account of swelling. After the forms have been struck they should be thoroughly cleaned and oiled before being used again.

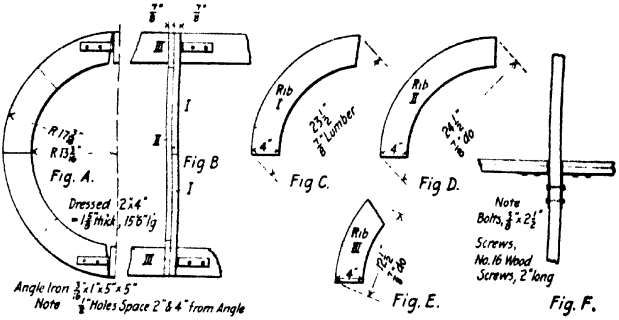
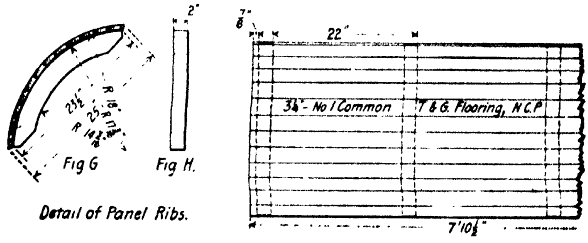


Fig. A.
Fig B
Fig C.
Fig D.
Fig. E.
Fig. F.
Rib I
Rib II
Rib III
Dressed 2x4" - 1⅝ thick, 15'6" lg
Angle Iron ⅜"x1"x5"x5"
Note ⅝" Holes Space 2" & 4" from Angle
Note
Bolts, ½"x2½"
Screws, No. 16 Wood Screws, 2" long

Details of Circles



Details of Panels.

FIG 155.—Details of full round forms, Louisville, Ky.

Two-stage Operations.—It is usually necessary to construct sewers and drains having flat bottoms in at least two operations, because of difficulty encountered in getting the required smooth finish on the invert, if the concrete for both invert and arch is poured at one time.

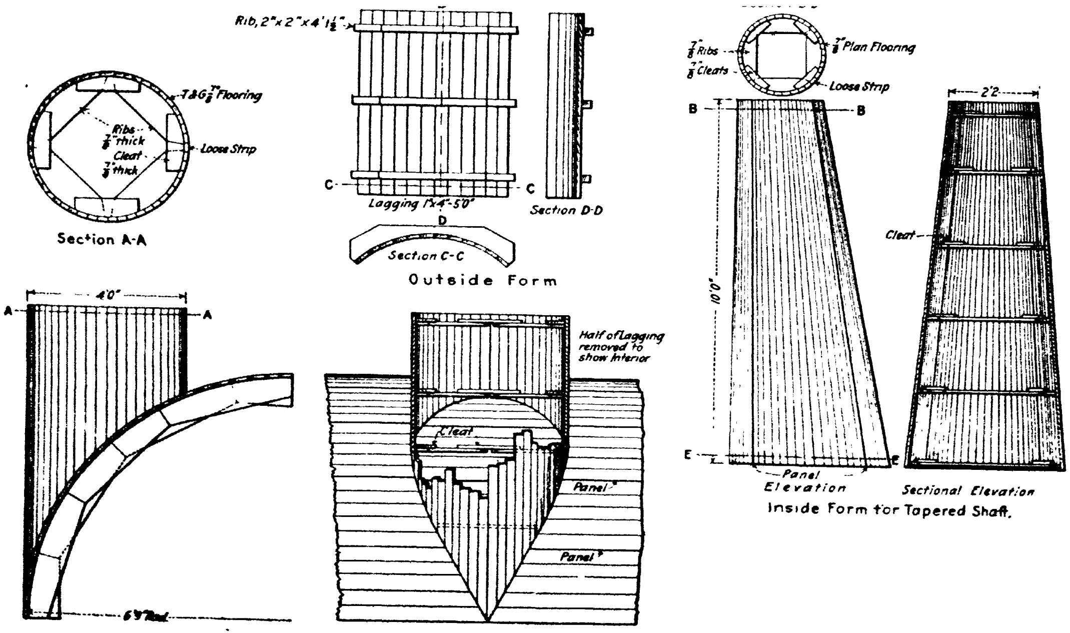
In Louisville a 12 ft. × 12-ft. semi-elliptical sewer, Fig. 141, was very successfully built in two operations. The invert and side walls, 26 in. high, were run first, the concrete extending back to the sheeting thus avoiding the use of outside forms. The lowest set of trench timbers, which came 4 in. above these walls, was removed 48 hours later, the concrete thereafter serving to brace the sheeting. Four days after the arch was poured the centers were collapsed and moved ahead, through other forms in place, and set up ready for another run.

When a sewer is so large that it cannot be built in two operations because the trench braces cannot be removed without endangering the stability of the banks, the structure must be built in three or more operations, *i.e.*, invert, side walls and arch. This is also true where the design of the sewer requires the construction of walls which are straight or nearly straight, as in horse-shoe shaped sewers, and it may also apply to reinforced concrete sewers where it is necessary to place certain portions of the steel from time to time as the concrete is placed. Occasionally large sections are built in one operation, as was the case on the 17-ft. Kensico aqueduct of the Catskill system of the New York water works (see *Eng. Record*, May 3, 1913).

SPECIAL FORMS

Forms for Manholes.—It is entirely practicable to build satisfactory manholes of concrete, although in many cases it is probably cheaper and more convenient to build them of brick. Fig. 156 shows the forms necessary for constructing a concrete manhole upon a sewer 13 ft. 6 in. in diameter. These forms provide for a manhole on the side of the sewer, which is the best location on large sewers. The manhole is 4 ft. in internal diameter at its base, and 2 ft. 2 in. at its top (an unusually large manhole). The lower portion is cylindrical and can be carried up to any desired height so that the same conical forms can be used for pouring manholes of different depths. These forms are collapsible, it being necessary only to remove the cleats holding the rib segments together when the lagged segments can be taken out, the strips of lagging over the joints not being rigidly nailed to the ribs.

Fig. 157 shows the forms necessary for building a concrete base for a brick manhole on a concrete sewer 36 in. in diameter. The section in that illustration shows the inside manhole form in place, attached to the sewer forms, after pouring both the concrete of the sewer and the concrete of the manhole base.



Elevations of Inside Forms for Base of Manhole.

FIG. 156.—Forms for concrete manhole, Louisville, Ky.

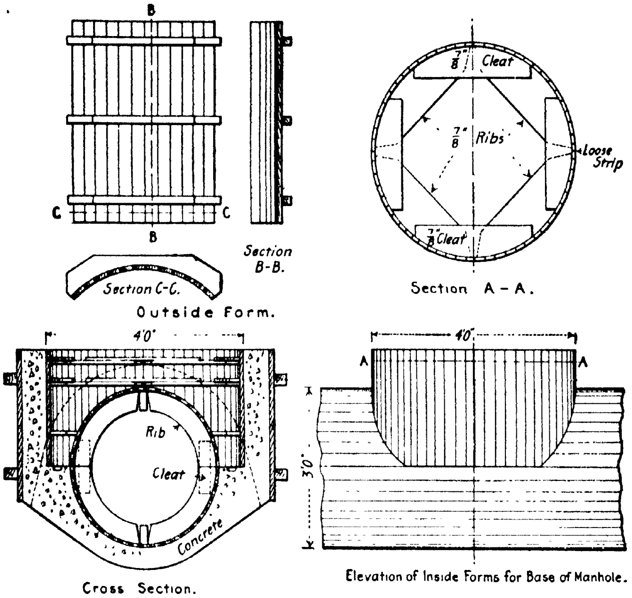


FIG. 157 —Form of manhole base, Louisville, Ky

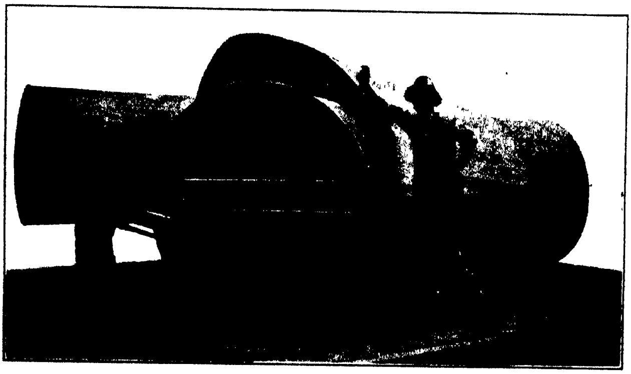


FIG. 158.—Wooden junction form for 5-ft. and 3-ft. connecting sewers.

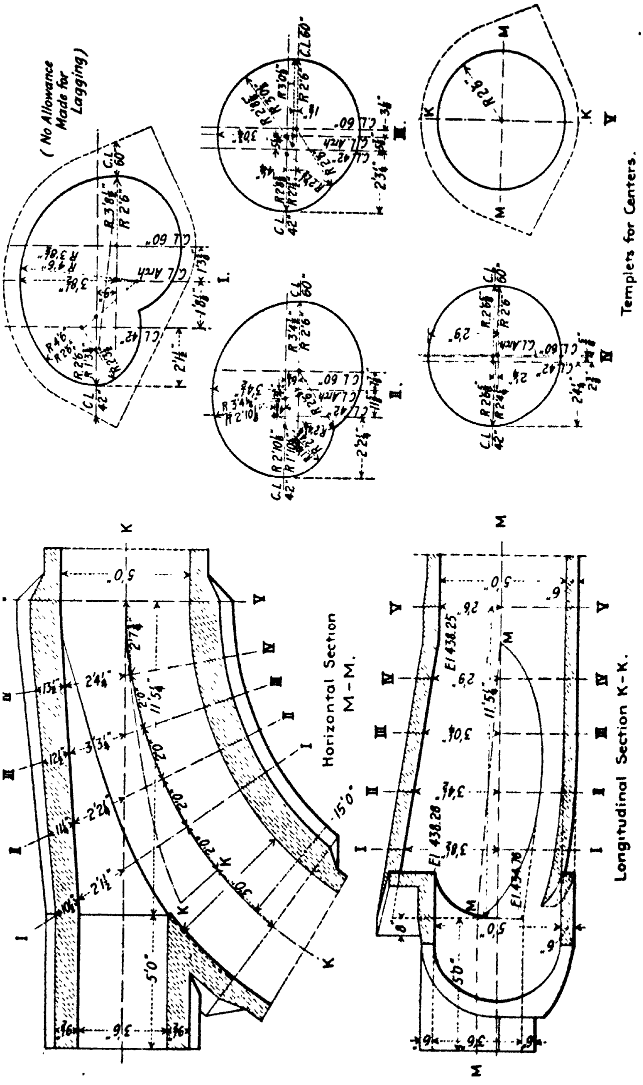


Fig. 159.—Dimensions of junction chamber built with form shown in Fig. 158, Louisville, Ky.

Forms for Curves and Junctions.—Where concrete is used for the construction of sewers it is probable that in many cases the special structures can be built more cheaply of brick, as much less form work will be necessary. It is practicable to build such structures of concrete, however, if found to be economical. Fig. 158 shows the inside forms used for the construction of a junction between two sewers, 5 and 3 ft. in size, respectively, the sewer below the junction being 5 ft. in diameter. Fig. 159 gives the dimensions of the forms required for this junction. As in most cases such forms can be used but once, they may be built in a less permanent and durable manner than forms which are to be used over and over. If care is used in laying out the ribs and in lagging them, a satisfactory finish and curvature may be obtained. It will be found that thin strips of lagging, from 1/2 to 3/4 in. in thickness, will be amply strong for the smaller sizes, say up to 8 ft. in diameter, and the curves can be made much more satisfactorily than with thicker lagging. In many cases, especially where the trenches are deep, it may be found desirable to put the ribs together and erect and lag them in the trench, as it will be found difficult, if not impossible, to lower forms already lagged and in large pieces into the trench on account of the large number of braces across it.

KIND AND QUALITY OF LUMBER FOR WOODEN FORMS

In an article entitled "Inspection of Forms and Centering" (*Eng. and Cont.*, vol. xxxvii, p. 201) Jerome Cochran gives many valuable suggestions pertaining to the making and use of forms for concrete construction. Many of these suggestions are applicable to forms used for the construction of concrete sewers. With reference to the kind of lumber to be used he states:

> "The kind of lumber to be used for forms depends upon the desired results and price. White pine, yellow pine, spruce, Oregon pine and redwood are suitable for forms. Yellow pine lumber is found to be excellent for forms; owing to the large amount of pitch contained, it absorbs water slowly and holds its shape. Norway pine and fir lumber are also suitable for forms for a similar reason. . . . . . For ordinary work, however, even for panels, white pine is generally apt to be too expensive, and other lumber should be substituted for it. Hemlock is unreliable and should be used only when absolutely necessary and then only in the roughest kind of work. Oak is hard to nail, expensive and imprints grain marks on the concrete even when the form is thoroughly wetted.
>
> ". . . . The lumber must not be so dry that when soaked by the concrete it will swell so as to bulge and distort the forms, nor so green that it will shrink so as to leave open joints that will show plainly on the face of the work. A slight tendency of this kind, however, may be checked by keeping the boards thoroughly wet with water until the concrete is placed.

Kiln-dried lumber, therefore, is not suitable for form construction because of its tendency to swell when soaked by the concrete, and green lumber is undesirable on account of liability to check and warp. Partly seasoned lumber is therefore the best. When it comes to a choice between green and dry lumber, green lumber is preferable because it is less affected by the water in the concrete.

". . . . The form boards used on all exposed surfaces should be of dressed lumber and closely fitted in order to secure the best results in appearance and surface finish of the work. The lumber for face work should be surfaced on one side and two edges and dressed on the face side to even thickness, and may be tongue-and-groove flooring or similar lagging. Tongue-and-groove boards, however, are more expensive than boards surfaced on one side and on the edges, which will generally answer for most work. A principal objection to the use of tongue-and-groove lagging is that there is no opportunity for it to expand, and, again, the planks are particularly hard to place a second time.

"For backing and other rough work undressed lumber may be used. Undressed lumber should be used where the concrete is to be plastered. In other words, forms for non-exposed surfaces may be rough lumber but should be water-tight."

COST OF WOODEN FORMS

There are a large number of varied elements which enter into the cost of the forms required for building concrete sewers, among which may be mentioned the rate of progress and the resulting length of forms required to complete the work in the prescribed time, the length of period which must elapse after concrete is poured and before forms may be struck, the amount of special form work which can be used but once, such as forms for junction chambers and curves, and the length and number of different sizes of sewers to be built under a given contract.

TABLE 68.—COST OF LABOR AND MATERIALS REQUIRED FOR BUILDING WOODEN CENTERS AT WORCESTER

Size	No. of centers	Cost per foot of center
24 in.	6	$0.225
28 in.	6	0.347
27×40 in.	4	0.473
48 in.	5	0.718
60 in.	8	0 768
69 in.	12	0.948

The cost of building centers suitable either for brickwork or for concrete sewers in Worcester, Mass., from 1902 to 1905, varying from 24 to 69 in. in diameter, is given in Table 68.

The cost of wooden forms varying in size from 36 in. in diameter to 6 ft. by 9 ft. 10 in., are given in Table 69. These costs are merely given for illustrative purposes and should not be used without careful checking against local conditions, for in addition to diversity in cost of labor and materials in different parts of the country, difference in prices may result from a variation in the length of sewer to be built with a given set of forms and the quantity of concrete per linear foot of sewer. If the sewer is of massive construction, requiring a large quantity of concrete per linear foot, the cost of forms per cubic yard of concrete will be relatively low, whereas if the sewer is of thin section, the cost per cubic yard of concrete for forms will be relatively high.

In building the sewer at Kalamazoo, Mich., item 4, the invert was formed by means of templets, to which the concrete was screeded. After the concrete had set, the arch forms were placed and the remainder of the concrete poured.

The South Bend sewer, item 5, was built by placing vertical lagging along the sides in line with the outside lines of the sewer, carrying it as high as the springing line of the arch. Invert templets equal in length to about one-third of the circle were set to line and grade and spaced 3 ft. apart. The invert was then completed to a point about 18 in. above the grade line. Side forms for the invert were then set, extending up to the spring line. After these forms were filled, the centers, made in two pieces, were set, together with jackets or outside forms, extending up on either side about 45 deg. from the springing line.

The sewer built in Waterbury, Conn., item 6, had vertical side walls and was formed by first laying down the invert and then placing forms upon it. The centers were composed of two sections, the first, 20 in. high, formed the side walls, and was rectangular in section. The center rested on top of this and outside forms were placed reaching about 45 deg. from the springing line.

At Worcester, the sewers were built by setting "formers," or ribs, to line and grade. The concrete forming the bottom of the invert was then roughly placed and 2-in. planks, shaped to conform to the curvature of the ribs and the sewer, were placed between the concrete and the under side of the ribs. After the bottom concrete was placed, these planks were brought up on the side, as fast as the concrete was poured. After the invert built in this manner had set sufficiently, centers were placed and the concrete of the arch poured, the concrete being held in position on the outside by "arch formers" similar to those used in forming the invert.

The water works conduit at Newark, N. J., item 11, was built in one operation. The forms were open at the bottom for about one-sixth of the circle, and this portion of the invert was shaped and screeded by hand. The outside forms consisted of steel angles, bent to the shape of the conduit and held at the bottom by stakes driven in the ground. The tops of these angles were held together by 1/2-in. tie rods. These angles had small lugs bolted onto them at intervals, which held 2-in. plank, slipped down as the concrete progressed.

It may be said, in a general way, that wooden forms required for building small concrete sewers, from 24 in. to 6 ft. in diameter, will

TABLE 69.—COST OF WOODEN FORMS FOR CONCRETE SEWERS

No.	Size	Length of sewer	Cost of lumber		Labor, making and maintaining		Labor, moving and placing		Total cost		Quantity of concrete per linear foot, cu. yd.
			Per ft of sewer	Per cu yd of concrete	Per ft of sewer	Per cu yd of concrete	Per ft. of sewer	Per cu. yd of concrete	Per ft. of sewer	Per cu yd. of concrete	
1	48 in.	855 ft	$0.24	$0.62	$0.22	$0.58	$0.46	$1.19	$0.92	$2.39	0.385
2	42 in.	1,414 ft.	0.12	0.42	0.16	0.55	0.43	1.48	0.71	2.45	0.29
3	36 in.	1,044 ft.	0.09	0.40	0.27	1.16	0.48	2.04	0.84	3.60	0.233
4	6 ft. × 9 ft. 10 in.	1,080 ft.	0.30[1]	0.32[1]			0.43	0.45	0.73	0.77	0.936
5	66 in.	2,464 ft	0.35[1]	0.59[1]			0.45	0.76	0.80	1.35	0.593
6	4 ft. 5 in. × 4 ft. 6 in.		0.17[1]	0.46[1]			0.16	0.43	0.33	0.89	0.371
7	24 in.	212 ft	0.13[1]								
8	28 in.	307 ft.	0.13[1]								
9	69 in.	627 ft.	0.29[1]								
10	60 in.	1,020 ft.	0.11[1]								
11	60 in.	3,850 ft.	0.18[1]	0.22[1]			0.48	0.60	0.66	0.82	0.805
12	Semi-circ. 72 in.	184 ft.	0.2216	0.57							
13	Junc. cham., 108 × 144 in. and 90 in.	18 ft.								4.00	39[3]

No	Place and year		Manner of construction of sewer	Reference	No	Place and year		Manner of construction of sewer	Reference
1	Louisville, Ky.	1911	1 Operation[2]	F. C. Williams	7	Worcester, Mass.	1905	2 Operations	H. P. Eddy
2	Louisville, Ky.	1911	1 Operation[2]	F. C. Williams	8	Worcester, Mass.	1904	2 Operations	H. P. Eddy
3	Louisville, Ky.	1911	1 Operation[2]	F. C. Williams	9	Worcester, Mass.	1903	2 Operations	H. P. Eddy
4	Kalamazoo, Mich.	1902	2 Operations	Handbook of cost data, Gillette	10	Worcester, Mass.	1902	2 Operations	H. P. Eddy
5	South Bend, Ind.	1906	3 Operations	Handbook of cost data, Gillette	11	Water works conduits, Newark, N. J.	1904	1 Operation	Handbook of cost data, Gillette
6	Waterbury, Conn.		2 Operations	Handbook of cost data, Gillette	12	Webb City, Mo.	1913		*Eng. & Con.*, 1913
					13	Louisville.	1910		*Eng. & Con.*, 1910

[1] Includes making of forms. [2] Sewer built with forms shown in Figs. 153, 154 and 155. [3] Total volume of concrete.

usually cost from 75 cents to $2.50 per cubic yard of concrete, and from 25 cents to $1.00 per linear foot of sewer.

COST OF STEEL FORMS

As in the case of wooden forms, the cost of steel forms varies greatly with local conditions, among which may be mentioned as particularly important the length of sewer which is to be built with a given set of forms and the type of forms to be used, whether standard or special.

In all parts of the United States east of the Mississippi River standard prices can be secured for standard apparatus, by which is meant forms for circular sewers of relatively small sizes. If the sewers are of large size or special design requiring the construction of forms for the particular work in hand, the prices may considerably exceed those quoted for standard forms.

To assist in making preliminary estimates of cost, prices of centers from 20 to 72 in. in diameter, which may be assumed to approximate the prices which can be obtained from manufacturers for centers to be used east of the Mississippi River, are given in Table 70. These prices should be used with caution as quotations may vary materially from time to time.

TABLE 70.—APPROXIMATE RENTAL PRICES OF PATENT SEMICIRCULAR STEEL FORMS 20 TO 72 IN. IN DIAMETER

Size	Price per linear foot of form
20 in to 30 in.	$1 00
36 in. to 48 in.	1 50
51 in. to 60 in.	2.00
63 in. to 66 in.	2 50
72 in. to 84 in.	4 00

Note.—The prices given cover the use of centers for a period of 9 months and include all freight charges so that the only additional expense to the contractor is that involved in unloading, hauling between the cars and the work and reloading the forms when the work is finished. For points west of the Mississippi freight rates from the eastern shipping points must be added to standard prices.

Most manufacturers usually send erecting foremen to superintend first erection and to instruct the user in the economical handling of the forms. In some cases where this is impracticable an additional charge is made if the user desires the assistance of an expert.

CLEANING FORMS PREPARATORY TO POURING CONCRETE

Forms should not only be made sufficiently strong to carry the loads imposed upon them, but they should be so made as to assure to the concrete a suitable surface. The inside surface of a sewer should be as smooth as it is practicable to obtain, and for this purpose the forms should be made smooth and water-tight. The outside surfaces need not be smooth, and therefore the forms may be made of rough lumber and need not be water-tight, although they should not allow any material quantity of water to run away from the mass of concrete.

The requirements of the contracts under which the Louisville sewers were built, from 1908 to 1911, stipulated that the forms must be so constructed as to insure a true and very smooth interior surface on the finished concrete, that the designs for the forms should be submitted to the engineer for approval before they were built, that care should be taken to prevent shavings, sawdust and other wastes resulting from the making of forms and centers from becoming embedded in the concrete, that forms should be thoroughly cleaned of cement and dirt and so prepared, or covered, that they might be readily removed, leaving the concrete with a smooth, presentable surface, and that they should be substantially water-tight.

Just before and after setting centers and forms such as those for side walls in order to complete a structure already partly built, particular care should be taken to clean the concrete surfaces upon which fresh concrete is to be placed. Sticks, chips, shavings, oil and dirt of all kinds accumulate on such surfaces during the placing of the forms. Sand, clay or other substances may fall from the banks or from hoisting and conveying apparatus, or it may be washed into the trench in times of storm. Concrete surfaces, particularly where reinforcement is used, are often hard to get at, shaded so as to be difficult to see, and in many ways hard to clean and inspect. Nevertheless they must be scrupulously cleaned if a good bond is to be secured. The authors have found sand pockets several inches long and thick and deep enough to permit running the hand several inches into the concrete at the junction of the side wall and arch. Under such conditions, it matters little upon what theories the design of the sewer is based.

LUBRICATION OF FORMS

There is a tendency for concrete to adhere to the forms and for a thin layer of it to break away from the structure, thus causing more or less roughness of the surface. To obviate this defect as far as possible, all the surfaces of forms which come in contact with concrete should be well oiled before the concrete is placed. Paraffine oil was generally used upon the work done in Louisville, Ky., and gave satisfactory results, especially with wooden forms.

During the cold winter months, when there is a tendency toward "peeling" where steel forms are used, it may prove desirable to use heavier oil, which will reduce this trouble. The use of such oil, however, is somewhat unsatisfactory as it adheres to the surface of the concrete after the forms are removed, making work inside the sewer dirty and disagreeable. Many different kinds of oil were used, with varying degrees of success, but it was found that the best results were obtained with cup grease where it was necessary to use a heavy lubricant.

On the Metropolitan Sewer System in Boston, where wooden forms covered with galvanized iron have been extensively employed, kerosene or coal oil has been used with satisfactory results.

Soap is sometimes used for lubricating forms, and is particularly useful in smoothing up forms for junction chambers and other special structures, where there are numerous angles and corners. Soft soap is well adapted for ordinary lubrication, and hard soap may be used to advantage in filling small spaces and irregularities in the forms.

Cochran suggests the use of petrolatum cut down with three parts of hot kerosene, for the ordinary oiling of forms. He also suggests that where forms are to be used repeatedly it may prove advantageous to oil them when new with three coats of boiled linseed oil, and where forms are for surfaces that are to be whitewashed, grouted, or plastered, a treatment with boiled soap applied hot may be preferable to treatment with oil or grease, as the soap will prevent adhesion of the concrete to the forms and will not injure the surface or diminish the strength of the concrete (*Eng. and Cont.*, vol. xxxvii, p. 201).

LENGTH OF TIME FORMS SHOULD BE LEFT IN PLACE

There is some difference of opinion among engineers and practical sewer builders as to the length of time forms should be left in place. This period depends upon temperature, humidity, the setting time of the cement, the size and character of the structure and the load to be placed upon it. During hot summer weather concrete ordinarily sets rapidly, and a period of from 24 to 36 hours will in most cases be sufficient for invert and side wall forms and 48 hours for arch forms. The time required for the concrete to acquire sufficient strength to permit the removal of the forms with safety will be shorter in summer than in winter when the concrete sets much more slowly. Centers should, of course, never be removed while the concrete is frozen. Forms used for large sewers and other similar structures should remain in place a greater length of time than forms for small sewers under similar conditions. In all cases and at all seasons of the year the trench should be backfilled to a height somewhat above the top of the sewer, probably 2 ft., before the arch forms are struck. This filling should be placed in relatively thin layers, uniformly on both sides of the arch, and thoroughly tamped.

The contracts under which the Louisville sewers were constructed specified that the centers should not be struck until the backfilling had been completed to the height of a horizontal plane 2 ft. above the top of the completed masonry, and that the centers should never be struck without the consent of the engineer upon the work. The length of time the centers were required to be left in place was varied according to the size of the sewer in question. For the larger sewers, ranging from 10 to 15.5 ft. in diameter, it was stipulated that the centers should remain in place 7 days. Upon smaller work, this time was reduced, the minimum for sewers from 2 to 6 ft. in diameter being 4 days. As a result of the Louisville experience, it is felt by the engineers upon this work that the length of time the centers were required to be kept in place might have been somewhat reduced under most conditions, without danger of injury to the concrete.

The side wall forms, which were used only upon the larger work, were required to be left in place until the concrete had acquired a hard set, which was usually from 24 to 48 hours after it had been poured.

In response to an inquiry regarding the practice of the Board of Water Supply of the City of New York in removing forms used in the construction of the cut-and-cover aqueduct, Alfred D. Flinn, Dep. Chief Eng. states:

"The specifications stipulate:

"Directions as to the time of removing forms shall be strictly followed and this work shall be done with great care so as to avoid injury to the concrete."

In general, directions were not given, the contractors not being required but allowed to remove forms, the average minimum time being after 24 hours during hot and favorable weather to 72 hours at the end of the season. Exceptions to this occurred, however, particularly in the case of slow-hardening and sticky cement, 72 hours being the average minimum time. This time for removing forms permitted desired progress with a minimum number of forms and made the work of finishing, where required, easier."

In December, 1908, Albert C. Lehman, Manager of the Blaw Steel Construction Co., of Pittsburg, Pa., published (*Eng. Record,* vol. lviii, p. 664) the opinions of engineers upon the length of time that centering should be left in place in concrete sewers. In giving their views, the engineers were requested to leave out of consideration differences in cement, the percentage of reinforcement and the depth of backfilling, that the replies might be as nearly comparable as possible. Sixty replies were received, the results of which appear in Table 71.

In Chicago, on a heavy concrete sewer 8-1/2 ft. in diameter, backfilling was permitted in 24 to 36 hours after placing concrete. Forms were removed in from 2 to 4 days. In Baltimore, centers 12 ft. 3 in. in diameter were removed in 48 hours, and earlier on some occasions.

TABLE 71.—OPINIONS OF ENGINEERS AS TO NECESSARY PERIOD OF TIME BETWEEN POURING OF CONCRETE AND STRIKING OF CENTERS UPON SEWER CONSTRUCTION

Diameter of sewer	Period of time in hours		
	Max.	Min.	
2 to 5 ft.	96	12	90 per cent. of reports in 36 hours
6 to 9 ft.	96	24	60 per cent. of reports in 48 hours
			30 per cent. of reports in 72 hours
10 to 12 ft.	144	48	90 per cent. of reports in 72 hours
16 to 20 ft.	240	48	60 per cent. of reports in 72 hours
			30 per cent. of reports in 96 hours

HANDLING FORMS

Wooden forms are usually made to collapse in sections 8 or 10 ft. in length. There is so little room for a man to work in sewers 30 in. or less in diameter that it has been found cheaper to remove the forms from the rear rather than try to take them ahead through other forms in place. A low flat car about 8 ft. in length and 12 in. in width, with a rope attached to each end, can readily be drawn back and forth as fast as the forms can be loaded and unloaded. This is quicker, cheaper, and keeps the forms in better condition than trying to drag them out, one on top of the other, as is often done. In flat bottom sewers, 5 ft. in diameter or larger, the forms may be carried out on cars run on temporary tracks.

When steel centering is used, special carriages or travelers, Fig. 160, are usually designed for carrying them ahead, as already described. These carriages may be provided with vertical jacks and collapsing side arms which are attached to the sides of the sections for pulling them in and away from the concrete. In operating the carriage for moving the forms, the vertical jacks are first run up until the yoke end of the jack engages the top hinge rod, the side arms then being swung into position and fastened to flanges near the springing line of the centers. The side arms are then drawn in and the vertical jacks lowered until the forms have assumed a position which will permit them to pass through the sections that are in place ahead.

The cost of handling forms in trench is a substantial portion of the cost of the masonry, a fact which should be borne clearly in mind when the forms are being designed, as the type of forms may have a very important influence upon this item of cost. The cost of handling forms, including erection, taking down, cleaning, and moving forward, varies greatly, but upon relatively small work, such as sewers from 2 to 6 ft. in diameter, it may be estimated at from $0.50 to $1 per foot of sewer. Further data upon this subject are given in Table 69 and the accompanying text.

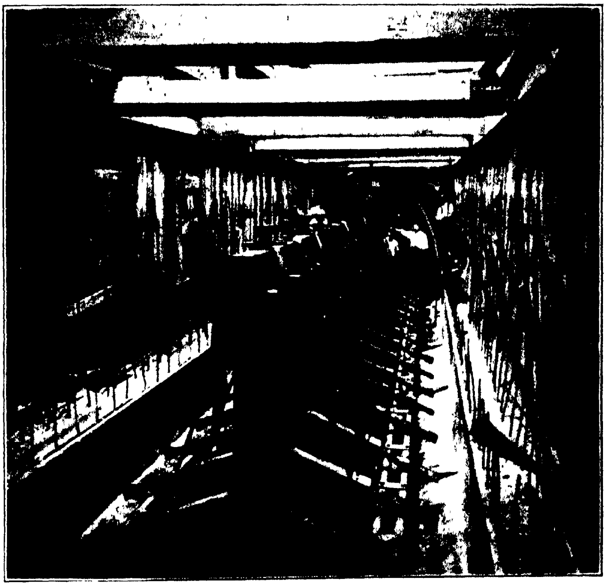


FIG. 160.—Traveler used in moving Blaw centers, Louisville, Ky.

(Facing page 432)

CHAPTER XVI

CONTRACTS, SPECIFICATIONS AND DRAWINGS

The construction of extensive municipal works is generally carried on by contract in order that the operations may be conducted by men who, it is assumed, are specialists in directing workmen and using machinery so as to accomplish the desired ends with a minimum expense. It is also usually assumed that there is not enough municipal work going on regularly to keep a large force of city workmen employed in an efficient way, and it is quite generally held that politics so interfere with the management of work carried on by the city itself that efficiency is impossible and even the quality of the work suffers. The authors do not hold such an extreme position, and after considerable experience in executing large and small sewerage work both by day labor under their direct charge and by contract, they have found such advantages and disadvantages in both systems that the choice between the two in any given case should not, in their opinion, be determined without a careful consideration of local conditions. Where the difficulties of construction are certain to be numerous or there must be frequent changes in some of the details of foundations, underdrains and the like to meet changes in the ground in the bottom of the trench, an experienced foreman with a force of good muncipal laborers will probably build a better small sewer than a contractor will construct. Where the work is without serious difficulty and the city is without experienced men to act as foremen, a contractor will probably build a good system at less expense than the city. Between these limiting conditions are many combinations of circumstances which it would be a waste of time to attempt to enumerate and discuss.

If a contractor is to be engaged, it is desirable to prepare a form of contract, a set of specifications and enough plans to make perfectly clear just what the city wishes and the contractor agrees to do. Unfortunately the English language is sometimes used so poorly that the meaning of a clause in a contract cannot be understood by city or contractor, and this meaning must then be determined by judge or jury. For this reason, therefore, clearness of wording and correctness in drafting are highly desirable.

Even when a requirement is perfectly clear, a controversy may arise over its legality or equity. The city of New York has endeavored to avoid such disputes by writing into its general form of contract a clause meeting every litigated case in which it has been a loser through an adverse judicial interpretation of contract requirements. The resulting mass of legal verbiage is almost incomprehensible to a layman, and as it has not been copied elsewhere its necessity is doubtful. The legality of a contract of importance should always be passed upon by a lawyer, for he is generally more familiar than the engineer with the forms of wording which have been adjudicated and have a definite meaning in consequence. The engineer, however, will do well to follow as closely as possible all suits which will throw light on the proper wording of contracts and specifications, for if well informed he can do much toward rendering litigation over a contract a waste of time.

These two sources of controversy over a contract and its accompanying plans and specifications should be kept in mind when preparing such documents. The relations between all parties and their respective duties should be made definite in every detail. The work to be done should be clearly explained. If the surface of a concrete wall is to be left perfectly smooth and free from checks, pits, scars and stains, this should be stated, for the requirement that the wall shall be built in a workmanlike manner satisfactory to the engineer is not definite. If a machine is desired, those parts and features which are really needed should be described, leaving the rest to the manufacturer, for it is not a good description to say that the machine shall be of somebody's make, or equal. These loose expressions are fast disappearing from the specifications of leading engineers, as it is becoming appreciated that there is a great difference between a description prepared to explain in a general way the purpose and design of a public work and a description of what a contractor must supply and do. Fairness to both owner and contractor demands a complete, precise and clear description, either in words or by drawings, of every detail of the undertaking which is not left to the contractor's judgment. By following this policy and by requiring inspectors to be fair and not harsh in enforcing contract requirements, a city gains a reputation for enlightened business methods which results in low prices from responsible contractors.

Essentials of a Contract.—The essential elements of all contracts have been very clearly outlined by John Cassan Wait in his "Engineering and Architectural Jurisprudence:"

> "Every binding contract must contain four essential elements, viz.: 1. Two parties with capacity to contract. 2. A lawful consideration; a something in exchange for its legal equivalent; a *quid pro quo*. 3. A lawful subject-matter, whether it be a promise, an act, or a material object. 4. Mutuality: a mutual assent, a mutual understanding, and a meeting of the minds[1] of the parties. These elements of a simple contract are of the

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[1] Where there is some error or omission in the plans or specifications, there can have been no "meeting of the minds" of owner and contractor on this point. Frequently an

foundation of the English common law, and no agreement, so-called, is a binding contract unless it embodies each and all of these essentials. Without them our courts decline to recognize the binding effect of the agreement and the parties are free to fulfil their obligations or not at their pleasure."

Capt. D. L. Hough, in a paper on "The Relations of Engineers and Contractors," presented before the First American Road Congress, at Richmond, Va., Nov. 21, 1911, expressed himself as follows:

> "The very essence of a contract is mutuality; and the more this most important principle of a contract is kept before our minds, the more faithfully will the contract be carried out and the less will be the friction developed. In fact .... if the mutuality of a contract is kept always before us, and it is understood that when a contract is once signed the parties thereto have equal rights thereunder, are on an equal footing, and that there is nothing in contractual relations that places the party who pays with his money on a higher plane than the party who pays with his materials and services, or *vice versa*, and if the engineer considers himself a non-partisan arbitrator, there is nothing left to be desired.
>
> "In so far as the engineer lays out, directs and inspects the character of materials and workmanship, he is properly the representative of the principal; but under the terms of those clauses where he is made the arbitrator, interpreter and estimator, he is the representative of both parties and should be absolutely non-partisan.
>
> "Actually, therefore, the engineer, in so far as he is the arbitrator, that is, is made the final court of appeal under the terms of the contract by both contractee and contractor, he is the employee of both and must not be partisan; and if he is partisan, he is not faithful to the trust reposed in him by the other party, however shocking this statement may sound to those obsessed by the present practice."

In order to facilitate its use, that portion of the contract which treats of the work involved, in which all the details are specifically mentioned, is usually segregated and submitted as "Specifications," either within the body of the contract or supplementary to it. There is no general agreement in regard to the items that should be included within the specifications as distinguished from the main contract. If the specifications are submitted separately there should be a clause in the contract calling attention to the fact that the specifications and the plans explanatory of

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attempt is made to bridge over such a difficulty by a general clause that where such cases are of minor importance both parties agree to accept the engineer's decision, but this clause is of no real importance in case of controversy because it does not indicate who shall decide whether the importance of the point at issue is "minor." It is much better, when an error or omission is discovered, to prepare a brief memorandum, dated and signed by both parties, stating that it is mutually agreed that the meaning of the specifications shall be interpreted in a certain way, or that a sketch firmly attached to the agreement shall be considered a satisfactory substitute for a detail on the original drawings. If the error or omission involves work of a class for which no unit price was bid, it is highly desirable to have a written agreement concerning the price before it is undertaken.

them must be considered as part of the contract. In such a case the plans and specifications must be so described in the contract that in case of litigation oral testimony to identify them will not be necessary. Claims for extras can be kept down in this way.

Although contingencies are a proper subject of contract, yet it has been held by the courts that they must be clearly referred to in the contract, as a contractor is not bound to assume a risk not mentioned in the agreement. Where specifications are obscure or when several parts of them are in conflict, "custom" will be held by the courts to govern in such cases. The determination of "custom" usually costs far more and is less satisfactory to everybody than a little more expense in making the contract requirements clear and harmonious.

Blanket clauses have probably been the source of as much controversy in the execution of contracts as any other provision, and should be avoided so far as possible. In contracts requiring a long period of years for execution, it is difficult to anticipate all conditions to be met. Labor and market conditions change, and modifications in the laws and ordinances existing at the time of contract often occur. The contract and specifications must, therefore, be sufficiently flexible to care for these, without bringing undue hardship upon either party to the work. Where blanket clauses are required to cover such emergencies, it is of importance that anticipated contingencies be mentioned and that as definite provision be made for their settlement as is possible.

One danger of any alterations in a contract as the work progresses is that they may operate to relieve a surety from his responsibility in case the contractor fails to execute the work. Where the surety bond is an integral part of a contract, there are really three parties to it, and all three must agree to any changes. This has led some lawyers making a speciality of engineering relations to advise preparing supplementary contracts whenever changes are necessary, or drawing up written agreements that certain features of the contract shall be interpreted as having carefully defined meanings. It is wise for the engineer and his entire staff to avoid very carefully making any oral statement which may be construed as altering any contract or specification requirement, for such a statement made in the presence of witnesses may be used to prove the inadequacy or imperfection of the written agreement should the contractor wish to withdraw from it. In short, a contract is a very important obligation, and there are the best of reasons for the old rule that no alterations in it shall be made except in writing, with legal advice, and no orders shall be given for work to be done under blanket clauses or provisions for extras, except in writing, carefully worded and completely defining the extent of the work.

"Some contractors exhibit an unusual willingness to carry out the most erratic directions of the engineer. This is done in order to break away from the contract and set up a claim that, by reason of change of plan, the contract has been annulled and a new basis of compensation is necessary. This is chicanery, to be sure, but the engineer should be able to recognise it. Claims against public corporations have many times been treated with excessive liberality, and they should not be allowed to succeed without the engineer's approval."—Albert J. Himes, Trans. Am. Soc. C. E., vol. lvi, p. 104.

Arbitration.—It is generally desirable that the contract should provide for a means of settling such disputes as may arise under it without recourse to the courts, except as a last resort. There has been much discussion about whom these disputes should be referred to, because most contracts provide that such questions shall be referred to the engineer. Contractors look upon most engineers as interested parties or as employees of the party of the first part, and have a feeling that, as such, the engineer is bound to cater to the interests of his employer and cannot, therefore, give an unbiased opinion. Contractors frequently express the opinion that engineers, in interpreting the provisions of contracts drawn by themselves, are likely to be biased by this fact, especially if the sufficiency of the contract is at issue. On the other hand, no other person than the engineer can have such complete and intimate knowledge of the details of the proposed undertaking and the provisions of the contract.

In interpreting the requirements or intent of any contract the engineer ceases to be the agent of the owner and becomes a judge with the owner and contractor at bar. If the engineer's decisions be strictly judicial, difficulties which come up in the progress of the construction work will often be readily and satisfactorily settled without need of further arbitration.

The appointment of an arbitrator, or a board of arbitrators selected from absolutely disinterested parties, has been suggested frequently as a panacea for such disputes, but the following are some of the difficulties in the way of securing satisfactory results by this method. First, cost; second, the difficulty of acquainting the arbitrator with all the facts, conditions, and influences surrounding a given contract, knowledge of which is necessary for rendering an impartial judgment; third, the law will not compel the carrying out of the provision, therefore the surety which is implied by the clause may be misleading either to the contractor or the contractee. This has been clearly expressed by John C. Wait, in his "Notes on the Law of Contracts," published jointly with "Specifications and Contracts" by J. A. L. Waddell in 1908:

"The writer's experience with contract clauses providing for arbitration is that in nine cases out of ten, when controversies have arisen, one or the other of the parties will refuse to carry out the provisions for arbitration.

This they may do with impunity, as there is no means of compelling them, under the ordinary provisions of the contract, to carry out the terms of the submission to arbitration; and they may, without generally subjecting themselves to any damages whatever, decline either to appoint arbitrators or to attend an arbitration. If, however, they do take part and the award be made and served upon the parties, they are irrevocably bound by such an arbitration. The trouble is and will be that they will refuse either to appoint arbitrators or to attend or take any part whatever; or one of the parties will seek to limit the scope of the arbitration to those matters and things in which he feels the stronger, eliminating and refusing to arbitrate matters which are apparently against him.

"Owing to this fact the use of the arbitration clause might as well be omitted, as the parties, if willing to arbitrate, can at any time come to terms of an arbitration for the settlement of their controversies, and the use of the clause under the circumstances deceives and misguides the contractor and sometimes the owner in the belief that he can require the other party to submit their differences to a board of arbitrators to be selected in accordance with the terms of the contract.

"Neither party to an arbitration can appeal from the decision of the arbitrators when it is once made and communicated to the parties. No appeal can be had by either party to the courts, unless gross fraud and collusion are shown between the arbitrators and one of the parties or the engineer and architect. The award by arbitrators is final and conclusive upon the parties, without appeal, if the award was fairly and honestly made."

Nevertheless, serious disputes have sometimes been satisfactorily settled by reference to single referee, an engineer of sound and ripe judgment, judicial temperament, and good standing.

While arbitration clauses in contracts are not very common, they have been used in some cases and are of interest to engineers preparing contracts and may be helpful to those who feel that arbitration should not be confined to the engineer in charge of the work. Several such clauses follow.

Jersey City Water Supply Co., Jersey City, N. J., 1902. (Completion of Main Dam at Storage Reservoir at Boonton, N. J., Contract 3.)

(p. 13) "Art. 3. Engineer the Referee.—All the work under this contract shall be done to the satisfaction of the Engineer, who shall in all cases determine the amount, quality, acceptability and fitness of the several amounts of work and materials which are to be paid for hereunder, and shall decide all questions which may arise. . . . .
and his determination and decision thereon shall be final and conclusive, subject only to revision by arbitration as provided under Art. 26."

(p. 48) "Art. 26. Arbitration.—In the event of disagreement between the Company and the Contractor, they shall submit the matter to arbitration, the Company choosing one arbitrator, and the Contractor one, and the two thus chosen to select a third. The decision of such arbitrators, or a majority of them, shall be made in writing to both parties, and when so made shall be binding on the parties thereto. The entire expense of such arbitration shall be borne by the party against whom the decision is rendered, or in event of a compromise decision, shall be borne by both parties in such proportion as the arbitrators may decide. Such arbitration is intended to avoid litigation and a written offer to submit thereto by either party, followed by such arbitration (if said offer is accepted and acted upon within twenty (20) days after the same is made), shall be a condition precedent to any action at law by either party under this contract."

Pittsburgh, Pa., Department of Public Works, Bureau of Filtration, Contract 1 (1905) for Filters, Basins and Appurtenances. (The Director exercises throughout the authority usually vested in the Engineer.)

(p. 557) "Right of Appeal.—It is expressly covenanted and agreed that in case any question or dispute shall arise between the parties under said Contract, or touching the quantity, quality or value of any work done or materials furnished thereunder, the same shall be referred to the Director of the Department of Public Works, whose decision thereon shall be final and conclusive; unless either or both parties shall, within ten (10) days thereafter, appeal from said decision in writing and shall notify both the Director and the other party of such appeal, in which case the said question or dispute shall be referred to two (2) arbitrators, one (1) to be selected by the Contractor and the other by the Mayor of the City of Pittsburgh, and both parties shall waive and release all right of action and suit at law or otherwise.

"In case of appeal, the party appealing shall file with the said Director a written statement of all matters in dispute and specify the particulars objected to, and the said appellant shall, with his or its appeal, state in writing the name of the arbitrator selected by him or it, and the other party shall, within ten (10) days of the notice of such appeal, notify the said Director in writing of his or its selection of an arbitrator, whereupon the said two arbitrators shall, after notice, proceed without delay to hear and determine the question or dispute in case they agree, render a decision thereon in writing, which decision shall be final and conclusive; or, if they fail to agree, then they shall select a third arbitrator and the three (3) arbitrators shall proceed to hear and determine the question or dispute and render a decision thereon in writing, and their decision or that of a majority of them, shall be final and conclusive.

"In case the party appealing shall not so name his or its arbitrator, the appeal shall not be considered. If the other party shall, within ten (10) days after date of notice of such appeal, fail to appoint his or its arbitrator, then the party appealing may apply to the Court of Common Pleas, No. 2, of Allegheny County, Pennsylvania, for the appointment of an arbitrator for such party in default, or by Bill in Equity, in the nature of a specific performance of the duty. If the two (2) arbitrators fail to agree upon a third arbitrator, then the persons constituting the Court of Common Pleas, No. 2, of Allegheny County, Pennsylvania, or a majority of them, may make said appointment and in case the persons constituting said Court of Common Pleas, No. 2, shall fail or refuse upon application to so appoint, the Mayor of the City of Pittsburgh shall make said appointment.

"When there are but two arbitrators, if they shall agree, their decision shall be final and conclusive. When there are three arbitrators, the decision of a majority of them shall be final and conclusive. The expense of such arbitration shall be paid by the City of Pittsburgh and one-half (1/2) of such sum shall be deducted from the amounts due or to become due the party of the second part."

Cincinnati, Ohio, Contract 86 (1906). "Proposals for the Construction of a Head House, Chemical House, Filter House, Valve Houses, and of a Wash Water Reservoir, and other miscellaneous work in connection therewith" for the Board of Trustees, Commissioners of Water Works.

(p. 65) "Arbitration.—It is agreed that in the event that said Trustees shall have ordered any alteration or modification of the within contract, and said Contractor and said Trustees cannot agree upon the price to be paid for the work or materials under such altered or modified contract, they shall thereupon submit the matter to arbitration, the Trustees choosing one arbitrator and the Contractor one, and the two thus chosen to select a third; and the award of such arbitrators, or a majority of them, as to the prices to be paid, shall be made in writing and entered on the minutes of said Trustees, and when so entered shall be binding on the parties hereto. And it is expressly understood and agreed that, in case of any alterations or modifications, so much of this agreement as is not necessarily affected by such alterations and modifications shall remain in full force upon the parties hereto. And the said Contractor hereby agrees not to claim or bring suit for any damages, whether for loss of profits or otherwise, on account of not being allowed to do such work or furnish materials as agreed upon prior to such alterations or modifications."

"All the work under this contract shall be done to the satisfaction of the said Trustees, who shall in all cases determine the amount, quality, acceptability, and fitness of the several kinds of work and materials .. .. .. and such determination and decision, in case any question shall arise, shall be a condition precedent to the right of the contractor to receive any money hereunder."

London County Council, Contract 3 (1907), for Low Level Sewer 2, North Side.

(p. 23) "Arbitration Clause.—Lastly, if at any time before completion of the work, any question, dispute or difference shall arise between the Council or the Engineer on their behalf and the Contractor as to the construction of this Contract, or as to any matter or thing arising under or out of this Contract, then such question, dispute or difference (unless it relate to matters and things which are under the terms of this Contract left to the final decision, requisition, certificate or order of the Engineer) shall be referred to the determination of the Engineer, whose decision shall be abided by until the completion of the work, when such questions, differences and disputes may as hereinafter provided for be referred to the decision of the arbitrator.

"If on completion of the work there shall remain any question, difference or dispute upon any of the matters or things referred to or specified in the first part of this Clause, or as to payments to be made to the Contractor, the same shall be referred to the award and decision of some person to be mutually agreed upon, or failing agreement to some engineer to be appointed by the President for the time being of the Institution of Civil Engineers, whose decision shall be final and conclusive between the parties. The provisions of the Arbitration Act, 1889, shall apply to any arbitration under this clause."

GENERAL FORM OF ENGINEERING CONTRACTS

The general method of contracting for engineering work is to invite proposals, either by means of a general advertisement or by solicitation. As announcements generally state that only that proposal which is considered most advantageous to the owner will be accepted, while the right is reserved to reject any or all proposals, contractors are induced to figure their proposals as low as possible, thereby securing to the owner the benefit of close competition. In order that all proposals may be in such form as to be readily compared it is desirable that bidders be required to submit their proposals on a form furnished by the owner. It is also desirable that a complete statement should be made by the owner setting forth the general scope and requirements of the work, in order that all contractors who bid upon the work may have a clear conception of it and bid upon the same thing. This should be furnished under the caption, "Information to Bidders."

Advertisement of Contract.—Although notice of impending work may be given to the contractors through an advertisement in the public press, the expense of advertising will prohibit the giving therein of all information needed by the bidder. It is therefore sufficient to cover in the advertisement a general statement of the work to be done, its location, the time and place of canvassing the bids, and of beginning and completing the work, the security required for its performance, the place where plans and complete specifications, including full information to bidders and proposal blanks, may be obtained, the name of the party inviting the proposal, and, if the work be of a public nature, the act or ordinance by virtue of which the work is undertaken.

The Information for Bidders should contain the facts covered by the advertisement and all of the information essential to the contractor for a general understanding of the requirements of the contract. The following subjects should be covered:

First, time, place and manner of submitting and withdrawing proposal. Second, reference to use of blank forms furnished by the owners for submitting bids. Third, the surety required, and the form of bidder's bond or certified check, the amount and character of surety required, method of draft, payment and return. Fourth, the name or names of the surety to be offered, in case of award of contract. Fifth, the methods to be adopted for the notification of the successful bidder. Sixth, general description and location of the work involved, statement of the quantity involved in each of the several subdivisions. Seventh, quantities are approximate only and are given to serve as the basis for comparison of bids, and the owner reserves the right to increase or decrease the amount of any class or portion of the work, preferably within stated limits. Eighth, bidders are required to satisfy themselves by personal examination of the conditions existing and the materials to be encountered at the site of the work. Ninth, qualifications required of the bidder as to experience, capacity, and financial resources. Tenth, reservation of right to reject any and all bids. Eleventh, such other requirements as local conditions may demand. Twelfth, statement that all bids submitted on blanks, other than those furnished by the owner, and all bids in which the conditions on the owner's blanks have been modified, may be rejected.

Form of Proposal.—The proposal should be made upon a printed form furnished by the owner, the object being to secure all the proposals in exactly the same form and to make sure that all prices are submitted in the same units, otherwise it will be difficult to compare the bids. The proposals must be delivered at the place designated to bidders at or before the hour named therein. They should be sealed and should not be opened until the time specified, and then generally, and preferably, in public. They should all be self-explanatory, and no opportunity should be given for oral explanation. Bids should generally not be allowed to be withdrawn or modified after the time set for the opening of the bids.

The following form has been found satisfactory by the authors:

To the of the Town of .. . .

For the construction of sewers in

The undersigned as bidder . , declare that the only parties interested in this proposal as principals are named herein, that this proposal is made without collusion with any other person, firm or corporation, that no officer of the Town or any person in the employ of the Town is directly or indirectly interested in this bid, that . . he . ha , carefully examined the location of the proposed work, the annexed proposed form of contract and the plans and specifications therein referred to and ... he ... propose . . and agree . that if this proposal is accepted . he... will contract with the .... in the form of the copy of the contract deposited in the office of said .... and attached hereto, to provide all necessary machinery, tools, apparatus and other means of construction, and do all the work and furnish all the materials specified in this contract in the manner and time therein prescribed and according to the requirements of the Engineer as therein set forth, and that he will take in full payment therefor the following sums to wit:—

Item 1a. For all earth excavation, etc .. . .

Item 17. For extra work, if any, performed in accordance with Article XXII of the annexed form of contract, the reasonable cost of the work as determined by the Engineer, whose determination shall be final, plus fifteen per cent (15 %) of such cost.

If this proposal shall be accepted by the .. . .. and the undersigned shall fail to contract as aforesaid, and to give a bond in the sum of five thousand dollars ($5,000), with surety satisfactory to the . ..., within six days (not including Sunday or a legal holiday) from the date of the mailing of a notice from the ... to him, according to the address given herewith, that the contract is ready for signature, then the .... may at their option determine that the bidder has abandoned the contract and thereupon the proposal and acceptance shall be null and void, and the certified check for five hundred dollars ($500) accompanying this proposal shall become the property of the Town of ....; otherwise the accompanying check shall be returned to the undersigned.

Form of Bidder's Bonds.—Each bid must be accompanied either by a certified check drawn for the stated amount or by a bidder's bond given by an acceptable surety company, providing that if the contract, for which proposal is made, shall be awarded to the bidder, the bidder will enter into the contract in accordance with the terms of the proposal and will give bond for the amount stated in the information to bidders for the faithful performance of the contract; and, to that end, that the said surety company shall, in case the bidder shall fail to execute the contract and furnish bond, pay to the owner as liquidated damages the amount stated in the information to bidders.

Contract.—The contract must be made in accordance with the terms of the Advertisement, Information for Bidders, and Proposal, and although these are not embodied within the limits of the formal contract it should be stated in the contract that they, together with the specifications and surety bond, shall be considered as integral parts of the formal contract. No changes should be made either in the form of contract or in the items which appear in either the Advertisement, Information for Bidders, or Proposal as submitted by the bidders, in making out the contract, as by so doing the bidder may be relieved from the obligation of entering into a contract with the owner, on the ground that his offer was not accepted in its original terms and that there is therefore no binding contract.

Bond.—The form of bond printed after the typical contract reproduced later in this chapter has been found to meet the general requirements of sewerage work. (See page 462.)

INSURANCE

The old theory of employers' liability is rapidly giving way to the more modern theory of workmen's compensation. There follows a transcript from the 1912 Year Book of the New International Encyclopedia, which gives a statement of the present status of these two theories.

"**Workmen's Compensation.**—This is a term used to designate that form of compensation for industrial accidents which has come to replace employers' liability. Under the older system the employer was required to compensate a workman injured while in employment only when the employee could show in a suit at law that the employer had been grossly negligent, that the worker had not been negligent, and that the accident was not due to the carelessness of a fellow employee. Under the common law the employer was securely entrenched behind the rules of assumed risks, contributory negligence, and the fellow-servant doctrine. Employers' liability laws gradually reduced the employer's security by modifying these doctrines in various respects, but still imposing on the injured worker the necessity of bringing suit in court. The employers at the same time insured themselves against such suits in employers' liability insurance companies, which assumed the obligation of fighting the employees' suits and of paying penalties imposed. Thus the worker was forced to assume the costs of repeated law suits before he could secure any damages. Statistics showed that not more than 45 per cent. of the premiums paid by employers to insurance companies were finally paid to injured workers. Moreover, actual statistical investigation showed that between 60 per cent. and 70 per cent. of injured workers received no compensation whatever. Even when compensation was secured, the expenses involved so reduced it that the remainder was wholly inadequate to offset the economic loss involved in the injury itself. Thus many families were permanently reduced to a lower standard, even to permanent poverty, by industrial accidents. The compensation principle introduced into England and continental countries 15 to 20 years ago has within the past 2 years found extensive adoption in the United States.

"The advantages of the compensation principle may be briefly summarized as follows: (1) It furnishes certain, prompt, and reasonable compensation to injured workers and their dependents; (2) it removes from the courts the numerous cases growing out of employers' liability litigation; (3) it relieves charity of the poverty due to uncompensated accidents; (4) it is more economical, since the costs of lawyers, witnesses, insurance companies, and court trials are eliminated, and because it gives to the worker a much larger proportion of the cost to employers; (5) it increases good will and stimulates accident prevention; (6) it furnishes a basis for accurate statistical knowledge of phases of industrial and social life heretofore neglected."

Liability Insurance.—Liability insurance is usually written under one of four principal heads, employers' liability, public liability, team insurance, and automobile insurance.

In employers' liability insurance the insurer agrees to indemnify the insured against loss by reason of liability imposed by law upon him for damages on account of bodily injuries, including death, at any time resulting therefrom, accidentally suffered by reason of the prosecution of the work, at the places described in the policy and under the classification covering an employee of the assured.

Public liability insurance differs from the above only in the fact that it insures against injuries sustained by other parties than those employed by the assured, that is, the public.

By team insurance the insurer indemnifies the assured against loss by reason of liability for damages on account of bodily injuries to his drivers and to the public caused by means of draught or driving animals or vehicles in the service of the assured, while in the charge of the assured or his employees. Automobile insurance applies to automobiles in much the same way as team insurance applies to animal-drawn vehicles.

Liability insurance premiums are based upon the amount of pay rolls. When the policy is issued the contractor estimates the probable amount of his pay roll during the term of the policy, and a certain percentage of this pay roll is charged as a premium, this percentage varying with the hazard of the work. At the end of the period for which the policy is drawn, the insurance company calls for an audit of the contractor's pay rolls, in order to determine the exact amount of those pay rolls upon which the premium estimated is adjusted. Although in a general way the foregoing is the method adopted, modifications are made to fit each particular case.

The cost of liability insurance covering bodily injury depends upon the laws regulating the liability of the contractor directly, and indirectly that of the liability insurance company.

Sewer construction is generally classed as more hazardous than much other contract work. The 1913 insurance rates in Massachusetts, under the compensation act, were as follows:

For work less than 7 ft. in depth,	
Insurance of laborers.	$4 87 per $100 of pay roll
Insurance of public..	2 00 per $100 of pay roll
Total insurance of employees and public	$6.87
For trenches 7 ft. or more in depth,	
Insurance of contractor's employees.	$6 75 per $100 of pay roll
Insurance of public..	3 00 per $100 of pay roll
Total.	$9.75 per $100 of pay roll
Masonry structures	$3 75 per $100 of pay roll
Insurance of public	1.25 per $100 of pay roll
Total.	$5 00 per $100 of pay roll
For employees handling explosives	$18 75 per $100 of pay roll of such employees
Insurance of public.	$5 00 per $100 of pay roll

The foregoing rates for insurance of contractor's employees cover the payments required by the workingmen's compensation act. The rates on insurance covering the public guarantee the payment to injured persons of such sums as may be paid by the Insurance Company in voluntary settlement of claims, or as may be awarded by the court. The liability in such cases largely governs the payments and is not covered by the workingmen's compensation act.

In some cases the question has been raised whether a contractor shall have an allowance for premiums paid on liability insurance, where extra work is being performed and paid for at cost plus a percentage or fixed sum. It has been held by some attorneys that the contractor cannot recover for such expense, in cases where there is no workingmen's compensation act, unless specifically mentioned in the contract because it covers simply injuries due to the negligence of the contractor, which is not a legitimate portion of the expense of carrying out the work. While there seems to be ample justification legally for this opinion, such a course would undoubtedly work a hardship to most prudent contractors, who feel that liability insurance is an absolute necessity. To avoid disputes on this point and provide a perfectly fair basis of adjustment of cost, contracts should specifically state whether or not the cost of liability insurance will be included in the cost of work paid for upon a cost plus percentage or fixed sum basis.

KINDS OF CONTRACTS

There is a variety of contracts due to the different methods of determining the compensation of the contractor. Among them may be mentioned: (*a*) the unit price, (*b*) the lump sum, (*c*) cost plus a percentage, (*d*) cost with a guaranteed limit, plus a percentage, (*e*) cost plus a fixed sum, and (*f*) cost plus a fixed sum, with a bonus if the cost is less and a deduction if it is greater than a fixed amount.

Unit Price Contract.—The unit price contract is probably more used than any other in sewerage work because of its provision for changes in the amounts of different classes of work which cannot be determined accurately in advance of construction. Where this system is employed, the engineer estimates as accurately as possible the amount of each class of work and the contractor bids a unit price on each class. The amount of his proposal is obtained by figuring the total cost of each class of work on the contractor's bid and then adding these totals together. It is impossible for the engineer to estimate accurately all of these quantities, and the Invitation to Bidders should always contain a statement that the owner does not guarantee the accuracy of such estimates nor that the borings represent accurately the quality of the materials to be excavated, and prospective bidders should be required to ascertain the working conditions by personal investigation of the site. The importance of this is shown by the following notes of a suit over a unit price contract.

The Commissioners of Sewerage of Louisville advertised for bids for the construction of a sewer and awarded the contract to the lowest of the four bidders, each of whom bid a given price per item. The successful bidder formally executed the contract and offered a bonding company as surety in the sum of $8000, accepted by the commissioners. The contractor prosecuted work for several months, when he abandoned the contract. The Commissioners of Sewerage then advertised for new bids and relet the contract to the lowest of the new bidders, at an alleged loss of $20,353.33. The commissioners brought action against the original contractor to recover this loss, which was the difference between the latter's bid upon the estimated quantities of work to be done, excluding the amount of work already done by the first contractor, and the bid of the party to whom the contract was awarded the second time. The bonding company was made a party defendant. The defendants resisted recovery, on the ground that the contract should be cancelled because of a mutual mistake of the parties to it.

The case was carried to the Kentucky Court of Appeals, where the final decision contained the following comments on this important feature of such contracts:

"The plans upon which bids were invited showed borings indicating that the material to be encountered, through which the sewer would run, was blue clay, whereas it was claimed to be something else; the plans represented that the material to be encountered in the trench was solid, whereas it was soft and semi-fluid. In the approximate quantities, it was estimated by the engineer that 4100 ft. of timber foundation would be required, whereas, in fact, about 22,000 ft. of timber foundation was used. It is claimed by argument that this miscalculation caused the defendant to bid less on another item, to wit, excavation, than it would otherwise have done. . . .

"Appellant . . . agreed to do the construction work according to certain plans and specifications. Prior to the letting of the contract, appelees had taken samples of the subsoil by means of a hand-auger, at points along the line of the work about 200 ft. apart. The locations of these borings are shown on certain blue-prints. . . . The material parts of the 'Information for Bidders' are as follows:

"'The following is an approximate statement of the extent of the work required, based upon the estimate of the engineer; the several bids will be computed, tested and canvassed by the quantities of work given in the statement, viz., . . . (the various items of the contract). . . . These quantities are based upon the construction of the sewer in open cut, are approximate only, being given as a basis for the comparison of bids, and the Commissioners of Sewerage do not expressly or by implication agree that the actual amount of work will correspond therewith, but reserve the right to increase or decrease the amount of any class or portion of the work as may be deemed necessary by the engineer. . .

"'As the above mentioned quantities, though stated with as much accuracy as is practicable in advance, are approximate only, bidders are required to submit their estimates upon the following express conditions, which shall apply to and become part of every bid received, viz., bidders must satisfy themselves, by personal examination of the location of the proposed work, and by such other means as they may prefer, as to the actual conditions and requirements of the work and the accuracy of the foregoing estimates of the engineer, and shall not, at any time after the submission of an estimate of the engineer, dispute or complain of such statement or estimate, nor assert that there was any misunderstanding in regard to the nature or amount of work to be done.

"'The excavation, the masonry and other parts of the work have been divided into classes and items in order to enable the bidder to bid for the different portions of the work in accordance with his estimate of their costs, so that in the event of an increase or decrease in the quantities of any particular class of work the actual quantities executed may be paid for at the price bid for that particular class of work.'

"Reduced to its final analysis, appellant's complaint is that he encountered difficulties in excavation that he did not anticipate. By the express terms of his contract, this was a risk that he assumed. The appellees not only furnished him with all the information that they had on the subject, but put him on notice that in the event he encountered unforeseen difficulties, he could make no claim on that account. Having taken the work upon a unit basis as to prices, and it not being within the power of either party to foretell with any degree of accuracy the character of difficulties to be encountered, the contract was a chancing bargain, and the fact that he met with greater or less difficulty than was anticipated by the parties would not entitle either to a cancellation of the contract. . . ."

Lump-sum Contract.—Under the lump-sum contract the contractor agrees to furnish, for a definite lump sum of money, all labor and materials necessary to complete a certain definite piece of work to be built upon the detailed plans and specifications submitted or bid upon.

This method of contracting has the advantage that the owner should know from the start how much money will be involved by the work as planned. If changes are made in the plan, detail, or method of construction of, or in the kind or quality of materials required for, the work, modifications in contract price may and generally do result, with the possibility of disagreement and expensive litigation. Therefore more careful preliminary study of conditions is necessary in this form of contract than where the others are employed. Moreover, in this form of agreement, the contractor is likely to figure into his bid a safe margin to cover unforeseen difficulties, which the owner is obliged to pay, whether such hazards arise or not. If these hazards do not arise, the contractor may make a sum in excess of his normal and desired profit; and if the work does not prove to be hazardous, but especially favorable, a still further profit is secured. In any event, the element of uncertainty is likely to be given greater weight in preparing a bid than with the unit price type of contract.

Percentage Contract.—In order that the owner may assume all risk and per contra obtain full advantage of especially favorable circumstances, the percentage form of contract and its various modifications have been devised.

Under the percentage form the contractor agrees to furnish all labor and materials necessary to complete the entire undertaking at its actual cost plus an agreed and stipulated percentage of such cost. A serious disadvantage of the percentage form of contract is that there may be no spur to the contractor to do the work as expeditiously as possible and to keep the labor force and purchase of materials within limits most economical for the owner. To avoid this contingency the cost plus fixed sum form of contract has been used.

A form of contract was introduced in New Orleans in 1914 by George G. Earl to secure some of the special advantages of construction by day labor without abandoning the services of a contractor, which were practically required by local laws. Under it the contractor offers to furnish the labor and "such tools, material or equipment as may be needed," in addition to those supplied by the city, at cost plus a percentage. Non-resident labor, skilled or unskilled, cannot be supplied under such a contract so long as any resident laborers are ready, willing and able to do the work. The city furnishes the inspectors, foremen, timekeepers and pay-roll clerks. It has full supervision over this labor, "including the right to require the contractor to discharge any who are found unsatisfactory in quantity or character of work performed or insubordinate, and the right to fix their maximum rate of compensation, either per task or per diem, for each particular character of work or class of labor." An obvious danger in such a contract is met by the following provision:

"The labor furnished by the Contractor shall at all times consist of the most experienced men available at the rate of pay approved by the Sewerage and Water Board for each character of employment, and so long as any laborer already employed is willing to retain his position at said rate of pay and is satisfactory to the Supervisor furnished by the Board, he shall be retained by the Contractor so long as his services are needed, and inexperienced men or men not heretofore engaged upon work of a similar character, shall only be employed by the Contractor when no men of satisfactory record and experience are available at the rate of compensation offered."

This form of contract was first tried for sewer and water main extensions and services and house drains late in 1914. After extensive advertising but one bid, amounting to $748,579.90, was received for carrying out this work in the usual manner. On the percentage basis just described, five bids were received, ranging from 3.9 to 6.9 per cent. The work of putting in house drains and services is so cut up and the extent of the work on each job is so uncertain in advance of its prosecution, that there are manifest disadvantages in executing it on a unit price basis. The lowest bid on the percentage basis came to $492,487.02, or $256,092.88 less than the only bid under the usual system.

Cost-plus-fixed-sum Contract.—Under this form of contract the contractor agrees to furnish labor and materials and complete the entire undertaking at its actual cost plus a fixed and stated sum to cover the contractor's profit and perhaps other specified items. Apparently it is for the contractor's interest to execute the work as quickly as possible in order that he may earn his commission or profit within the shortest practicable time, but actually, where the contractor is carrying on several operations of this sort, the incentive to make speed may be trifling.

Under this plan the owner may regulate the class and amount of labor employed, the methods of execution, and the kind and quality of material to be purchased, and if he cares to he can regulate the entire rate of expenditures and thus indicate the speed desired in the execution of the work. It is to the contractor's interest, in view of possible future work, that this work be done in the most satisfactory and efficient manner; his self-interest is involved in that of the owner, provided the owner is likely to have the placing of another job, which should induce expeditious and economical work.

The legal status of contracts of this character has not been established by courts of final jurisdiction as yet (1914). The general opinion is that the contractor becomes some sort of agent, but until the subject has been thoroughly reviewed judicially, no definite statement can be made. In a suit under such a contract, which did not go beyond the trial court, one phase of such an agreement was shown to be important. The owner discharged the contractor before the work was finished, and was sued for the full "fixed sum" and a large additional amount, the contractor claiming that he had estimated the fixed sum at 10 per cent. of the cost of an undertaking which the owner subsequently quadrupled. The attitude of the court was that if this could be proved to the satisfaction of the jury, the latter should increase the sum due to the contractor beyond that stipulated in the contract. It was also stated by the contractor in his testimony that he was able, from his experience, to estimate the cost of work very accurately in advance and that his "fixed sum" was figured just as in lump-sum contracts except for the omission of all expenses he would incur for financing his work under the latter form, the inference to be drawn from his testimony being that the owner gained nothing financially by the cost-plus-fixed-sum agreement.

Cost-plus-fixed-sum with Guaranteed Limit Contract.—To make it appear to the owner that the cost of his work may not exceed a certain limit, some contracts have been drawn up on the cost-plus-fixed-sum basis with a guaranteed limit of total cost. At first sight this form would seem to give to the owner the security which its name implies. The real effect is, however, to wipe out the good features of the cost-plus-fixed-sum contract in which the relation between the owner and the contractor is perfectly free and co-operative, tending to place the contractor in a position antagonistic to the introduction of work, either in the form of labor or materials, that was not definitely contemplated at the outset, in order to prevent the actual cost from exceeding the guaranteed limit. This form of contract is subject to some of the disadvantages of the lump-sum contract.

Cost-plus-fixed-sum, with Bonus if Less and Penalty if Greater than a Stated Amount Contract.—If it is feasible to formulate a definite plan before the award of the contract, so that comparatively accurate estimates of the costs of the work may be made, and if it is probable that but little variation from the original plan will be necessary, this form of contract may be desirable for creating a further incentive to decrease the cost of the work, and at the same time increase the contractor's profit without increasing the total costs to the owner.

LIQUIDATED DAMAGES AND BONUS CLAUSES

Nearly all sewerage contracts contain provisions for the payment by the contractor of liquidated damages for failure to complete the work within the time stipulated. Such a payment should not be in any sense a penalty or a fine for mere failure to conform to the requirements, but should be made for the purpose of reimbursing the party of the first part for damages actually sustained. These cannot ordinarily be ascertained with precision either before or after the award of the contract, for they are composed of many elements incapable of precise computation, such as the damage resulting from the lack of use of the sewer for the period of delay, or that due to the contractor's occupancy of the street in which the sewer is being built. These might be arrived at by an analysis of conditions, but in any event they would be matters of judgment, upon which wide differences in opinion might reasonably be expected. Another element, which is capable of closer estimate, is the actual additional expense of engineering and supervision due to the delay, but even the cost of these items cannot be known in advance and their determination, after the work is finished, is always a difficult matter and usually largely dependent upon assumptions as to the proper method of accounting, particularly with respect to the apportionment of overhead and general charges. For these reasons, it is customary for the two parties to agree in advance upon a per diem sum to cover such damages and to stipulate in the contract that they are to be liquidated upon this basis.

Unless there are statutory provisions in the state in which the work is being done, as in New York, for example, there appears to be no legal requirement for incorporating in the contract the bonus clause simply because provision is made for the payment of liquidated damages. The requirement that the work be finished at a fixed time appears to be no different in principle from any of the other requirements of the contract, and it seems to be one properly subject to agreement between the parties to the contract. Many engineers and contractors, on the other hand, feel that equity requires a bonus for completion ahead of time where liquidated damages are provided for delay. The authors do not concur in this opinion as applied to contracts carried out under ordinary conditions but the advantages of having the work finished ahead of time are often as great as those resulting from avoiding a corresponding delay.

One advantage of the bonus and liquidated damages clauses which is not often given the consideration it merits, is that they furnish an incentive to the contractor to push his work to early completion, which almost invariably inures to his benefit by reducing his overhead expenses, rentals on machinery and cost of pumping and incidentals, such as the wages of watchmen, timekeepers, water boys and other employees not actually engaged in excavation, pipe laying, placing of masonry and other activities which may properly be classed as productive work. The amount of bonus, or of bonus and saved liquidated damages combined, may be sufficient to enable the contractor to rent additional machinery and furnish improved organization so that the work can be done more expeditiously and at reduced cost to him.

Upon the work done by the Commissioners of Sewerage at Louisville, Ky., the first four contracts were drawn without the bonus clause, the other eighty-two contracts providing for both bonus and liquidated damages. Upon this work the bonus and liquidated damages were fixed at $25 per day, which sum was intended to cover with reasonable accuracy the cost of engineering and supervision due to delay. This sum was relatively small, especially on the larger contracts, and in no wise covered all damages sustained, but it is doubtful if a larger sum would have resulted in a net gain to the city. The amounts of bonus and liquidated damages paid and collected under the several contracts and their relation to the total amount paid to the contractor and of the total cost of each sewer will be found in Table 33, Chapter VII (Quantity and Cost of Excavation). The bonus paid on all contracts was $26,900, amounting to 0.82 per cent. of the total payments to the contractor and 0.72 per cent. of the total cost of the sewers built. The aggregate amount of damages was $66,614, amounting to 2.02 per cent. of the total payments to the contractor and 1.78 per cent. of the total cost of the sewers.

The clauses in the Louisville contracts relating to the extension of the contract time, liquidated damages and bonus were as follows:

> "The contractor shall not be entitled to any allowance by way of damages on account of any delay on the part of the commission . . . . . but in case of such delay or delay on account of . . . . ., or of extra work, the contractor shall be entitled to so much additional time wherein to perform and complete the whole or any portion of the work required under this contract on his part as the engineer shall certify in writing to be just."

"The time in which the various portions and the whole of this contract are to be performed and the work is to be completed is of the essence of this agreement, and for failure by the Contractor to satisfactorily complete the whole of the work contemplated and provided herein within the time set, the commission shall deduct from the payments due to the contractor the sum of twenty-five dollars ($25) for each day of the delay, which sum is agreed upon, not as a penalty, but as fixed and liquidated damages for each day of each such delay, to be paid in full and subject to no deduction. If the payments due the contractor are less than the amount of such liquidated damages, the contractor and his surety shall pay the balance to said commission.

"The contractor will be paid a premium of twenty-five dollars ($25) per day for each day that the whole work called for in this contract is completed to the satisfaction of the engineer prior to the contract time of completion."

In drawing contracts carrying bonus and liquidated damages clauses, it is important to provide for a reasonable extension of the time allowed for completing the work, to provide for delays resulting from changes in the plan and in the quantity of work required, and from delay of the party of the first part in furnishing plans, materials and access to rights-of-way and other premises. In the decision of the Court of Appeals of New York, in the case of Mosler Safe Co. *vs.* Maiden Lane Safe Deposit Co., the court stated that "where the parties are mutually responsible for the delays because of which the date fixed by the contractor for completion is passed, the obligation for liquidated damages is annulled and in the absence of some provision under which another date can be substituted, it cannot be revived." N. Y. Rep., Ct. Appeals, 199, 479. The court offered the suggestion, however, that the right to liquidated damages might be preserved by a provision allowing for extension of the time for delays not the fault of the contractor.

Clauses providing for the collection of liquidated damages and the payment of bonus, like many other provisions of a contract, make it of the utmost importance that the drawings and specifications be made clear and complete and that they be based upon a well-matured study of the work to be done, that there may be little or no change in requirements after the contract is awarded.

CONTRACT DRAWINGS

Contract drawings should show what work is to be done and not attempt to be record drawings, such as are sometimes prepared after construction is completed. It is out of the question to foresee, in every case, how deep piling should be driven, how wide and deep footings of special structures should be made where foundation conditions are poor, or how deep the shaft of each manhole must be made. There must be certain dimensions in many classes of work which are subject to frequent change, and it is better to show this in every case on the contract drawings than to show a "typical structure" without any indication of the dimensions subject to change.

All "lines of excavation" and similar indications of limits affecting payment should be shown carefully, and all information necessary to make their use clear should be lettered on the drawings. All standard castings and other supplies to be furnished under the contract should be shown clearly and completely.

Where all features of a structure or device, with a few exceptions, can be shown with satisfactory clearness on a small scale, but a much larger scale is needed to bring out the details of these exceptional features, the most satisfactory results are usually obtained by drawing the whole structure to the small scale and indicating the special details conventionally; then these details can usually be drawn on a much larger scale on the same sheet. There is a tendency to make drawings far larger than is desirable, in order that the details of a few features, often unimportant, can be shown clearly on the scale of the whole drawing.

In some offices it is now customary to make all drawings on such a scale that they can be reduced by photography to a much smaller size and still remain perfectly clear. To be successful in preparing drawings for this purpose, the draftsman must keep in mind constantly the appearance his drawing will present when the spacing between lines, the thickness of lines, and the size of letters and figures are reduced to the small scale. In the case of lettering it is not wise to attempt to have the reduced size of the letters less than one millimeter. If the drawing is to be reduced to a fourth of the size of the original, the "lower case" or small letters on the latter should be 4 millimeters high. Moreover, all the lettering on a drawing, except headings, titles and emphasized words, should be of the same height, if the drawing is to be reduced photographically; if this is not the case the differences in size of the letters make a bad appearance on a photo-reduced copy.

When the specifications have been completed, they should always be checked with the drawings, to make sure that everything is given on the latter which is stated in the former to be there, and *vice versa.* There is not so much opportunity for standardization of design in sewerage work as in some other branches of engineering; nevertheless there is a tendency in all drafting rooms toward the repetition of designs, even when the new use is not so appropriate as that for which the plans were originally drawn, and this final comparison of specifications and drawings acts as a check on too much of this reduplication.

The authors have found that the pamphlets containing "Information for Bidders, Contract and Specifications for Sewer Construction" can be printed most quickly at reasonable expense if the type used is a standard newspaper size set on a typesetting machine. These sizes are usually what are known as 6-point or 8-point, the former being employed in this volume for the typical specifications on page 464, and the latter for the quotations on page 447. The main headings in the pamphlet are set entirely in capitals, centered in the column, and the subheads, which are also centered, and the side heads at the beginning of paragraphs, are set in capitals and lower case letters. The convenience of the reader of such small type makes it desirable to have the text set in ordinary newspaper column width, which is about 2-1/4 in. (See page 463.) If a page of such type is given a length of 4-1/2 in., it has a good appearance on a sheet of paper 4 × 6-1/2 in. in size, the margins around the type are large enough for notes and alterations, and the pamphlet is of convenient size for the pocket. The pamphlets are bound in board covers, using wire for stitching, and a strip of black cambric is pasted on the back to strengthen the fold. Pamphlets of this style can probably be produced with the maximum rapidity attainable in a job printing office, and this speed is sometimes quite important. If the work is done in a hurry, the maximum charge for an edition of 100 should not exceed $1 per page, both blank and text, the binding and covers not being charged for; if several days' time is allowed for a pamphlet of 64 pages or more, the price should be much lower. In asking for prices on such work, it is usually desirable to request bidders to suggest methods of reducing the cost, for sometimes useful suggestions can be obtained in this manner.

A TYPICAL FORM OF CONTRACT USED BY THE AUTHORS

THIS AGREEMENT, made and entered into this ..... .day of .... in the year One Thousand Nine Hundred and Fourteen, by and between, ... and . . ... Board of Selectmen, duly constituted and elected, herein acting for the Town of .. and without personal liability to themselves, party of the first part, and ....part .. of the second part,

WITNESSETH, That the parties to these presents, each in consideration of the undertakings, promises and agreements on the part of the other herein contained, have undertaken, promised and agreed, and do hereby undertake, promise and agree, the party of the first part for itself, its successors and assigns, and the part .. of the second part for . ... and .. .. heirs, executors and administrators or successors, as follows:

Art. I. Wherever the words defined in this article, or pronouns used in their stead, occur in this contract and the specifications herein, they shall have the meanings herein given.

The words Party of the First Part, above designated, shall include any board, officer or agents properly authorised to act for said party in the execution of the work called for in this contract [If it is desired to designate the party of the first part specifically, as the Town or the Selectmen, these words should be defined. It is often preferable to do so where many contracts are made for the same party.]

The word Engineer shall mean the Engineers for the party of the first part, Metcalf & Eddy, of Boston, Mass., either acting directly or through their properly authorised agents, such agents acting within the scope of the particular duties intrusted to them.

Wherever in the specifications or upon the drawings the words "as directed," "as required," "as permitted," or words of like import are used it shall be understood that the direction, requirement or permission of the Engineer is understood, and similarly the words "approved," "acceptable," "satisfactory" or words of like import shall mean approved by or acceptable and satisfactory to the Engineer

The word Contractor shall mean the party of the second part, above designated, or the legal representative of said party or the agent appointed to act for said party in the performance of the work.

The figures given in the contract and specifications or upon the drawings after the word elevation or abbreviation of it shall mean the distance in feet above the datum adopted by the Engineer.

Art II. To prevent disputes and litigations, the Engineer shall in all cases determine the amount, quality, acceptability and fitness of the several kinds of work and materials which are to be paid for under this contract; shall determine all questions in relation to said work and the construction thereof, and shall in all cases decide every question which may arise relative to the fulfillment of this contract on the part of the Contractor. His estimate and decision shall be final and conclusive upon said Contractor, and in case any question shall arise between the parties hereto, touching this contract, such estimate and decision shall be a condition precedent to the right of the Contractor to receive any money under this contract.

Art. III. The Engineer shall make all necessary explanations as to the meaning and intention of the specifications, shall give all orders and directions contemplated therein or thereby and in every case in which a difficult or unforeseen condition shall arise in the performance of the work required by this contract.

Any differences or conflicts which may arise between the Contractor and other contractors of the party of the first part in regard to their work shall be adjusted and determined by the Engineer

Art. IV. The Contractor shall do all the work and furnish all the materials, tools and appliances necessary or proper for performing and completing the work required by this contract, in the manner and within the time hereinafter specified. He shall complete the entire work to the satisfaction of the Engineer, and in accordance with the specifications and drawings herein mentioned, at the prices herein agreed upon and fixed therefor. All the work, labor and materials to be done and furnished under this contract shall be done and furnished strictly pursuant to, and in conformity with, the attached specifications and the directions of the Engineer as given from time to time during the progress of the work under the terms of this contract, and also in accordance with the contract drawings, which said specifications and drawings form parts of this agreement. The Information for Bidders hereto attached and the Proposal submitted by the Contractor are also made parts of this contract.

The Contractor shall conduct his work so as to interfere as little as possible with private business and public travel He shall, at his own expense, wherever necessary or required, maintain fences, provide watchmen, maintain red lights and take such other precautions as may be necessary to protect life and property, and shall be liable for all damages occasioned in any way by his act or neglect, or that of his agents, employees or workmen.

Art V. No night work requiring the presence of an engineer or inspector will be permitted, except in case of emergency, and then only to such an extent as is absolutely necessary, and with written permission of the Engineer, provided that this clause shall not operate in case of a gang organized for regular and continuous night work, and on work which can be, in the opinion of the Engineer, satisfactorily performed at night.

No Sunday work will be permitted, except in case of great emergency, and then only with written consent of the Engineer, and to such extent as he may judge to be necessary.

Art. VI. Whenever the Contractor is not present on any part of the work where it may be desired to give directions, orders may be given by the Engineer, and shall be received and obeyed by the superintendent or foreman who may have charge of the particular work in reference to which orders are given.

Art. VII. The plans and specifications are intended to be explanatory of each other, but should any discrepancy appear or any misunderstanding arise as to the import of anything contained in either, the explanation of the Engineer shall be final and binding on the Contractor. Any correction of errors or omissions in drawings and specifications may be made by the Engineer when such correction is necessary for the proper fulfilment of their intention as construed by him.

Art. VIII. Necessary sanitary conveniences for the use of laborers on the work, properly secluded from public observation, shall be constructed and maintained by the Contractor in such manner and at such points as shall be approved, and their use shall be strictly enforced

Art. IX. The Contractor shall not permit nor suffer the introduction or use of intoxicating liquors upon or about the works embraced in this contract.

Art. X. The Contractor shall commence work within 10 days after the execution of this contract by the board at such points as the Engineer may approve and shall thereafter continue it at such points and in such order of precedence as the Engineer may from time to time approve.

The rate of progress shall be such that the whole work shall be performed in accordance with the terms of this contract on or before . . . .

In case the Contractor fails to satisfactorily complete the entire work contemplated and provided for under this contract, on or before..... ......the party of the first part shall deduct from the payments due to the Contractor the sum of ten dollars ($10) for each calendar day of delay, which sum is agreed upon not as a penalty but as fixed and liquidated damages for each day of such delay, to be paid in full and subject to no deduction. If the payments due the Contractor are less than the amount of such liquidated damages, said damages shall be deducted from any other moneys due or to become due the Contractor, and in case said damages shall exceed the amount of all moneys due or to become due the Contractor, then the Contractor or his surety shall pay the balance to the party of the first part.

The rate of progress herein required has been purposely made low enough to allow for the ordinary delays incident to construction work of this character. No extension of time will be made for ordinary delays and accidents, and the occurrence of such will not relieve the Contractor from the necessity of maintaining these rates of progress.

The time in which this contract is to be performed and the work is to be completed is of the essence of this agreement.

Art XI. The party of the first part and the Engineer, agents and employees of the party of the first part may, for purposes already specified and for any other purpose, enter upon the work and the premises used by the Contractor, and the Contractor shall provide safe and proper facilities therefor. Other contractors of the party of the first part may also, for all the purposes which may be required by their contracts, enter upon the work and the premises used by the Contractor.

The Engineer shall be furnished with every reasonable facility for ascertaining that the work is in accordance with the requirements and intention of this contract, even to the extent of uncovering or taking down portions of finished work.

Art. XII. The inspection of the work shall not relieve the Contractor of any of his obligations to fulfil his contract as herein prescribed, and defective work shall be made good and unsuitable materials shall be rejected, notwithstanding that such work and materials have been previously overlooked by the Engineer and accepted or estimated for payment. If the work or any part thereof shall be found defective at any time before the final acceptance of the whole work, the Contractor shall forthwith make good such defect, in a manner satisfactory to the Engineer, and if any material brought upon the ground for use in the work, or selected for the same, shall be condemned by the Engineer as unsuitable or not in conformity with the specification, the Contractor shall forthwith remove such materials from the vicinity of the work. Nothing in this contract shall be construed as vesting in the Contractor any right of property in the materials used after they have been attached or affixed to the work or the soil, but all such materials shall, upon being so attached or affixed, become the property of the party of the first part.

Art. XIII. The Contractor shall employ enough competent men to do the work. If, in the opinion of the Engineer, the Contractor is not employing sufficient labor to complete this contract within the time specified, said Engineer may, after giving written notice, require said Contractor to employ such additional labor as may be necessary to enable said work to properly progress.

Art. XIV. The Contractor shall employ only competent men to do the work, and whenever the Engineer shall notify the Contractor in writing that any man on the work is, in his opinion, incompetent, unfaithful, disorderly or otherwise unsatisfactory, or not employed in accordance with the provisions of Article XV, such man shall be discharged from the work, and shall not again be employed on it, except with the consent of the Engineer. If, in the opinion of the Engineer, the Contractor is not employing sufficient labor to complete this contract within the time specified, said Engineer may, after giving written notice, require said Contractor to employ such additional labor as may be necessary to enable said work to properly progress. The judgment of the Engineer as to whether said work is progressing at such a rate as to enable it to be completed at the time herein specified shall be final and binding. Any action of the Engineer under this Article shall not affect the right of the party of the first part to annul this contract as provided in Article XX.

Art. XV. The Contractor shall keep himself fully informed of all existing and future State and National laws and local ordinances and regulations in any manner affecting those engaged or employed in the work, or the materials used in the work, or in any way affecting the conduct of the work, and of all such orders and decrees of bodies or tribunals having any jurisdiction or authority over the same; and shall protect and indemnify the party of the first part and its offices and agents against any claim or liability arising from or based on the violation of any such law, ordinance, regulation, order or decree, whether by himself or his employees.

Art. XVI. The Contractor, in the construction of the work, shall give preference in employment to citizens of the Town of . . . . . , and where citizens of said Town are not available, shall give preference to citizens of the State of. . . . . [In some states, municipal contracts are required to contain quotations from laws regarding employment of labor These should be inserted here For private contracts, this article can be omitted.]

Art. XVII. The Contractor shall give his personal attention constantly to the faithful prosecution of the work, shall keep the same under his personal control and shall not assign by power of attorney or otherwise, nor sublet, the work or any part thereof, without the previous written consent of the party of the first part, and shall not, either legally or equitably, assign any of the moneys payable under this agreement, or his claim thereto, unless by and with the like consent of the party of the first part.

Art. XVIII. The Engineer may make alterations in the line, grade, plan, form, dimensions or materials of the work, or any part thereof, either before or after the commencement of construction; if such alterations diminish the quantity of work to be done, they shall not warrant any claim for damages or for anticipated profits on the work that may be dispensed with; if they increase the amount of work, such increase shall be paid for according to the quantity actually done and at the prices stipulated for such work under this contract.

Art. XIX. The Contractor shall take all responsibility for the work, and take all precautions for preventing injuries to persons and property in or about the work, shall bear all losses resulting to him on account of the amount or character of the work, or because the nature of the land in or on which the work is done is different from what was estimated or expected, or on account of the weather, elements or other cause; and he shall assume the defense of, and indemnify and save harmless the party of the first part and their officers and agents, from all claims relating to labor and materials furnished for the work; to inventions, patents and patent rights used in doing the work; to injuries to any person or corporation received or sustained by or from the Contractor and his employees in doing the work, or in consequence of any improper materials, implements or labor used therein, and to any act, omission or neglect of the Contractor and his employees therein.

The Contractor shall carry liability insurance or workmen's compensation insurance, and also public liability insurance, together covering bodily injuries to his employees and the public received as a consequence of the performance of work under this contract

Art. XX. If the work to be done under this contract shall be abandoned, or if this contract or any part thereof shall be sublet without the previous written consent of the party of the first part, or if the contract or any claim thereunder shall be assigned by the Contractor otherwise than as herein specified, or if at any time the Engineer shall be of the opinion, and shall so certify in writing to the party of the first part, that the conditions herein specified as to the rate of progress are not fulfilled, or that the work or any part thereof is unnecessarily or unreasonably delayed, or that the Contractor has violated any of the provisions of this contract, the party of the first part may notify the Contractor to discontinue all work or any part thereof; and thereupon the Contractor shall discontinue such work or such part thereof as the party of the first part may designate and the party of the first part may thereupon, by contract or otherwise as it may determine, complete the work, or such part thereof, and charge the entire expense of so completing the work or part thereof to the Contractor; and for such completion the party of the first part for themselves or their contractors may take possession of and use or cause to be used in completion of the work or part thereof any of such materials, animals, machinery, implements and tools of every description as may be found at the location of said work.

All expenses charged under this Article shall be deducted and paid by the party of the first part out of any moneys then due or to become due to the Contractor under this contract, or any part thereof; and in such accounting the party of the first part shall not be held to obtain the lowest figures for the work of completing the contract or any part thereof, or for insuring its proper completion, but all sums actually paid therefor shall be charged to the Contractor. In case the expenses so charged are less than the sum which would have been payable under this contract if the same had been completed by the Contractor, the Contractor shall be entitled to receive the difference; and in case such expenses shall exceed the said sum, the Contractor shall pay the amount of the excess to the party of the first part.

Art. XXI. The Contractor shall pay to the party of the first part all expenses, losses and damages, as determined by the Engineer, incurred in consequence of any defect, omission or mistake of the Contractor or his employees, or the making good thereof.

Art. XXII. The Contractor shall do any work not herein otherwise provided for, when and as ordered in writing by the Engineer or his agents specially authorised thereto in writing, and shall, when requested by the Engineer so to do, furnish itemised statements of the cost of the work ordered and give the Engineer access to accounts, bills and vouchers relating thereto. If the Contractor claims compensation for extra work not ordered as aforesaid, or for any damages sustained, he shall, within one week after the beginning of any such work or of the sustaining of any such damage, make a written statement of the nature of the work performed or damage sustained, to the Engineer, and shall, on or before the fifteenth day of the month succeeding that in which any such extra work shall have been done or any such damage shall have been sustained, file with the Engineer an itemized statement of the details and amount of any such work or damage, and unless such statements shall be made as so required, his claim for compensation shall be forfeited and invalid, and he shall not be entitled to payment on account of any such work or damage.

For all such extra work, the Contractor shall receive the reasonable cost of said work, plus fifteen per cent of such cost, in accordance with Item 17 [The references to Items are to paragraphs under Art XXIV]

The decision of the Engineer shall be final upon all questions of the amount and value of extra work, and he shall include in such value the cost to the Contractor of all materials used, of all labor, common and skilled, of foremen and teams, and the fair rental of all machinery used upon the extra work, for the period of such use, which was upon the work before or which shall be required by or used upon the work after the extra work is done If said extra work requires the use of machinery not upon the work or to be used upon the work, then the cost of transportation of such machinery to and from the work shall be added to the fair rental, but said transportation shall not cover a distance exceeding .. miles. He shall include in the value of extra work the cost to the Contractor of employers' liability insurance or workmen's compensation insurance, and also public liability insurance, together covering bodily injuries to his employees and the public resulting from the extra work. The Engineer shall not include in the value of extra work any cost or rental of small tools, buildings or any portion of the time of the Contractor or his Superintendent, or any allowance for use of capital, these items being considered as being covered by the fifteen per cent. added to the reasonable cost

Art. XXIII. The party of the first part may keep any moneys which would otherwise be payable at any time hereunder, and apply the same or so much as may be necessary therefor, to the payment of any expenses, losses or damages incurred by the party of the first part, and determined as herein provided, and may retain, until all claims are settled, so much of such moneys as the party of the first part shall be of the opinion will be required to settle all claims against the party of the first part and their officers and agents, and all claims for labor on the work, and also all claims for materials used in the work or the party of the first part may make such settlements and apply thereto any moneys retained under this contract. If the moneys retained under this contract are insufficient to pay the sums found by the party of the first part to be due under the claims for labor and materials, the party of the first part may, at their discretion, pay the same and the Contractor and surety shall repay to the party of the first part the sums so paid out. The party of the first part may also, with the written consent of the Contractor, use any moneys retained, due or to become due under this contract for the purpose of paying for both labor and materials for the work, for which claims have not been filed in the office of the party of the first part. While it is understood that the security required to be given by the Contractor is furnished by the Contractor by his giving the bond accompanying this contract, the party of the first part may, nevertheless, if it shall deem it just and equitable so to do, cause any moneys retained, due or to become due, to be held and applied to the payment for labor or materials furnished or supplied by said Contractor *for which he has not made payment in full. The Contractor shall at such times as moneys are payable hereunder, deliver to the Engineer a sworn statement, showing as of that date the amount owing by him for materials and labor performed.*

Art. XXIV. The Town shall pay and the Contractor shall receive as full compensation for everything furnished and done by the Contractor under this contract, including all work required but not specifically mentioned in the following items, and also for all loss or damage arising out of the nature of the work aforesaid, or from the action of the elements, or from any unforeseen obstruction or difficulty encountered in the prosecution of the work, and for all risks of every description connected with the work, and for all expenses incurred by or in consequence of the suspension or discontinuance of the work as herein specified, and for well and faithfully completing the work as herein provided, as follows:

Item 1a. For all earth excavation for pump well, and earth excavation in trench from surface to depth of not over six (6) feet for sewers, manholes, and other appurtenances, including all sheeting, bracing, pumping, back-filling, resurfacing, etc., and the care of existing structures, precautionary measures and all other work incidental thereto, as required by the specifications, but not including the earth excavation for that part of the Harborside sewer to be constructed of cast-iron pipe, the sum of . ... ($...) per cubic yard.

Item 1b. For all earth excavation in trench below six (6) feet for sewers, etc. (as above stated) the sum of . . . . ($ . .) per cubic yard.

The items inserted here but not reprinted correspond with those in the "Information for Bidders" and the "Bid or Proposal "]

Item 17. For extra work, if any, performed in accordance with Article XXII of this contract, the reasonable cost of the work as determined by the Engineer, whose determination shall be final, plus fifteen per cent (15%) of such cost.

Art. XXV. The Engineer shall, once in each month, make an estimate in writing of the total amount of the work done to the time of such estimate and the value thereof. The party of the first part shall retain fifteen per cent of such estimated value as part security for the fulfilment of this contract by the Contractor, and shall monthly pay to the Contractor while carrying on the work, the balance not retained as aforesaid, after deducting therefrom all previous payments and all sums to be kept or retained under the provisions of this contract. No such estimate or payment shall be required to be made when, in the judgment of the Engineer, the total value of the work done since the last estimate amounts to less than three hundred dollars ($300). Payment may at any time be withheld if the work is not proceeding in accordance with the contract. The party of the first part may, if they deem it expedient so to do, cause estimates to be made more frequently than once in each month, and they may cause payments to be made more frequently to the Contractor. The party of the first part may at their option retain temporarily or permanently a smaller amount than is aforesaid, and may cause the Contractor to be paid temporarily or permanently from time to time during the progress of the work, such portion of the reserve as they deem prudent.

The Engineer shall, as soon as practicable after the completion of this contract, make a final estimate of the amount of work done thereunder, and the value of such work, and the party of the first part shall, within sixty days after such final estimate is so made and is approved by the party of the first part, pay the entire sum so found to be due hereunder after deducting therefrom all previous payments and all amounts to be kept and all amounts to be retained under the provisions of this contract, including the two per cent. of the amount of the contract to be retained as hereinafter provided for the making of repairs. All prior partial estimates and payments shall be subject to correction in the final estimate and payment.

It is distinctly agreed and understood that any changes made in the plans and specifications for this work, whether such changes increase or decrease the amount thereof or any change in the manner, time or amounts of payments made by the party of the first part to the Contractor, whether before or after the time for completion specified in this contract, shall in no wise annul, release, or in any way affect the liability and surety on the bond given by the Contractor.

The Contractor guarantees the work done under this contract, and that the materials used in the construction of the same are free from defects or flaws, and this guaranty is for a term of nine months from and after the date upon which the final estimate of the Engineer is formally approved by the party of the first part.

It is hereby, however, specially agreed and understood that this guaranty shall not include any repairs made necessary by any cause or causes other than defective work or materials in the construction of the sewers. The Contractor shall at all times within said term of nine months keep the surface of the ground over this work, or adjacent thereto, in the position and condition required by this contract, and refill any settlement or erosion in the back-filling or any surface graded by him due to any cause whatsoever, when so directed by the Engineer; should he fail to do so, the party of the first part may have said work done as described below.

Art. XXVI. The party of the first part may retain out of the moneys payable to the Contractor under this contract the sum of two per cent. on the amount thereof, and may expend the same in the manner hereinafter provided for in making such repairs of said work as the Engineer may deem expedient. If, at any time within the said term of nine months, any part of the work contemplated in this contract shall, in the opinion of the Engineer require repairing, the Engineer may notify the Contractor in writing, to make the required repairs. If the Contractor shall neglect to make such repairs to the satisfaction of the Engineer within three days from the date of giving or mailing such notice, then the Engineer may employ other persons to make the same. The party of the first part shall pay the expense of the same out of the sum retained for that purpose. Upon the expiration of the said term of nine months, provided that the work at that time shall be in good order, the Contractor shall be entitled to receive the whole or such part of the sum last aforesaid as may remain after the expense of making said repairs, in the manner aforesaid, shall have been paid therefrom, but if said expense is in excess of the sum of 2 per cent. retained, the Contractor shall pay to the Town the amount of the excess.

It is, however, agreed that the party of the first part may apply or keep the sum so retained to or for payment of other claims arising and made payable by the Contractor under the provisions of this contract but remaining unsatisfied.

Art XXVII. Neither the inspection of the party of the first part, or Engineer, or any of their employees, nor any order, measurement or certificate by the Engineer, nor any order by the party of the first part for the payment of money, nor any payment for, nor acceptance of, the whole or any part of the work by the Engineer or party of the first part, nor any extension of time nor any possession taken by the party of the first part or their employees, shall operate as a waiver of any provision of this contract, or of any power herein reserved to the party of the first part, or any right to damages herein provided; nor shall any waiver of any breach of this contract be held to be a waiver of any other or subsequent breach. Any remedy provided in this contract shall be taken and construed as cumulative, that is, in addition to each and every other remedy herein provided, and the party of the first part shall also be entitled as of right to a writ of injunction against any breach of any of the provisions of this contract.

Art. XXVIII. No person or corporation, other than the signer of this contract as Contractor, now has any interest hereunder, and no claim shall be made or be valid, and neither the party of the first part, nor any agent thereof, shall be liable for, or be held to pay any money, except as provided in Articles XX, XXII, XXIII, XXIV, XXV and XXVI. The acceptance by the Contractor of the last payment made as aforesaid under the provisions of Article XXV, shall operate as and shall be a release to the party of the first part and every agent thereof, from all claims and liability to the Contractor for anything done or furnished for, or relating to, the work, or for any act or neglect of the party of the first part or of any person relating to or affecting the work, except the claim against the party of the first part for the remainder, if any there be, of the amounts kept or retained as provided in Articles XXIII and XXVI.

Art. XXIX. The Contractor, by accepting and signing this contract, hereby expressly releases and discharges the individual members of the party of the first part and each and every employee or agent thereof, from any and all personal liability of every name and nature.

Art. XXX. The address given in the bid or proposal upon which this contract is founded is hereby designated as the place where notices, letters and other communications to the Contractor shall be certified, mailed or delivered. The delivering at the above named place or depositing in a post-paid wrapper directed to the above place, in any postoffice box regularly maintained by the Postoffice Department of any notice, letter or other communication to the Contractor, shall be deemed sufficient service thereof upon the Contractor. Such address may be changed at any time by an instrument in writing, executed and acknowledged by the Contractor and delivered to the party of the first part. Nothing herein contained shall be deemed to preclude or render inoperative the service of any notice, letter or other communication upon the Contractor personally.

In witness whereof, the said....... ... . party of the first part have hereunto set their hands and seals and the Contractor has also hereunto set his hand and seal, and the party of the first part and Contractor have executed this agreement in duplicate, one part to remain with the party of the first part and one part to be delivered to the Contractor this............day of ....in the year one thousand nine hundred and fourteen.

Town of.................... by
. ... (Seal)
... . (Seal)
BOARD OF SELECTMEN
.... (Seal)
.... (Seal)

A TYPICAL FORM OF CONTRACTOR'S BOND

Know all men by these presents,

That we . ... as principal: and . as surety, are held and firmly bound unto the Town of in the sum of Five Thousand Dollars ($5000) lawful money of the United States of America, to be paid to the Town of or to its attorney, successors or assigns, for which payment, well and truly to be made, we bind ourselves, our successors and our several and respective heirs, executors and administrators, jointly and severally, firmly by these presents

WHEREAS, the above bounden . . ... has made a contract with the Town of .. , bearing date the day of . 1914, to furnish material and labor for, and in good, sufficient and workmanlike manner, construct sewers in the Town of . . .. , together with all the work incidental thereto

NOW, THEREFORE, the condition of this obligation is such that if the said principal shall well and truly keep and perform all the agreements, terms and conditions of said contract on part to be kept and performed, and shall also pay for all labor performed or furnished, and for all materials used, in the carrying out of said contract, then this obligation shall be void, otherwise it shall remain in full force and virtue.

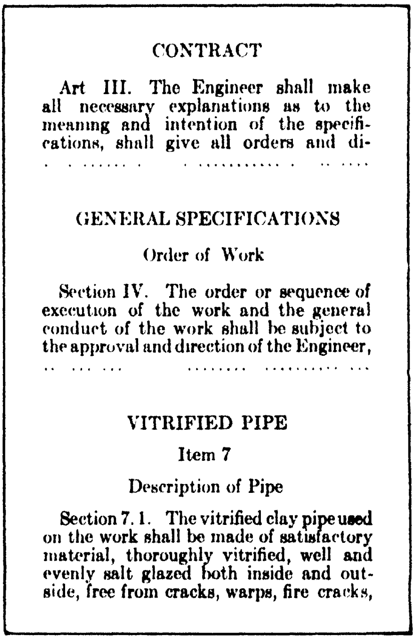
In witness whereof, the said of . . has hereto set hand and seal and the said . of . . .. has caused these presents to be executed by its duly authorised officers and its corporate seal to be hereto affixed this . day of . 1914.

. .. . (Seal)
CONTRACTOR.
... . (Seal)

Signed and sealed in the presence of . ...

TYPICAL GENERAL SPECIFICATIONS

It is the practice of the authors to print a descriptive head over each numbered clause in both the general and technical specifications prepared in their offices. Their purpose is indicated by a note at the beginning of the Contract, stating that such headings in the pamphlet containing the Information for Bidders, Contract and Specifications are intended only for convenience of reference, and do not form a part of either the Contract or Specifications. These headings are omitted in the following specifications, as each engineer will probably prefer to prepare his own, but they should always be inserted on account of the assistance they give in finding rapidly the requirements relating to any subject. For the same reason, a good index to the specifications is very desirable. The authors prefer to use Roman numerals to designate the clauses of the general specifications and Arabic numerals for the technical specifications. The clauses of a general nature which are given here must be considered merely as illustrative of the class of information appropriate under such a head, and not as models to be copied.



CONTRACT

Art III. The Engineer shall make all necessary explanations as to the meaning and intention of the specifications, shall give all orders and di-

. . . .

GENERAL SPECIFICATIONS

Order of Work

Section IV. The order or sequence of execution of the work and the general conduct of the work shall be subject to the approval and direction of the Engineer,

. . . .

VITRIFIED PIPE

Item 7

Description of Pipe

Section 7.1. The vitrified clay pipe used on the work shall be made of satisfactory material, thoroughly vitrified, well and evenly salt glazed both inside and outside, free from cracks, warps, fire cracks,

Excerpts from specifications illustrating typographical style and method of numbering clauses.

I. The work herein specified to be done consists of furnishing materials for and the construction of sewers in the village of . . . . , Town of . . . . , Maine.

II. The Contractor shall furnish and do everything, except as herein otherwise provided, necessary to complete the work in accordance with the terms of this contract and with the requirements of the Engineer thereunder. He is to make the requisite excavations for building the various structures; to do all ditching, pumping, bailing and draining, all sheeting, shoring, bracing, cofferdamming and supporting, all fencing, lighting and watching; to make all provisions necessary to maintain and to protect existing structures of whatever kind; to repair all damage done to such structures; to construct all brick, concrete, and stone work; to set in place ironwork; to refill excavations as required; to clear away all *rubbish and surplus material, and to furnish all materials, all tools, implements and labor required, and to do all other work necessary for the completion of this contract.*

III. All materials furnished and work done by the Contractor shall be subject to the inspection of the Engineer, and defective materials shall be removed from the site of the work and defective work repaired or replaced by order of the Engineer. Facilities for the handling and inspection of materials and work shall at all times be furnished by the Contractor and delays in handling the materials involving storage charges shall be at the expense of the Contractor, who shall provide suitable and adequate storage room for materials during the progress of the work and be responsible for any loss of or damage to materials furnished by him until the final acceptance of the completed work.

IV. The order or sequence of execution of the work and the general conduct of the work shall be subject to the approval and direction of the Engineer, which approval or direction shall, however, in no wise affect in the conduct of the work the responsibility of the Contractor.

V. All necessary lines, levels and grades shall be given to the Contractor, who shall provide at his own expense such forms, materials and assistance as may be required by the Engineer.

VI. All work shall conform during its progress or on its completion truly to the lines, levels and grades given by the Engineer and shall be built in a thoroughly substantial and workmanlike manner, in accordance with the plans and directions given from time to time by him, subject to such modifications and additions as shall be deemed necessary by him during its execution, and in no case shall any work in excess of the plan requirements and specifications be paid for unless ordered in writing by said Engineer.

All work done without lines, levels and instructions having been given therefor by the Engineer, or done during the absence of an assistant or inspector, will not be estimated or paid for except when such work is authorised by the Engineer in writing. Work so done may be ordered removed and replaced at the Contractor's sole cost and expense.

VII. The pipe grade line, or pipe water line, so called, is assumed herein to mean the bottom of the inside of the pipe, whether laid directly upon the ground or otherwise supported, and measurements of the depth of excavation (excepting rock excavation) shall be to a depth of two-tenths (0.2) of a foot below this grade line except where a concrete cradle is constructed, in which case it shall be to a depth of five-tenths (0 5) of a foot below said grade line. In the case of rock excavation the measurements shall be to a depth of five-tenths (0.5) of a foot below said grade line, except where a concrete cradle is constructed, in which case it shall be to a depth of thirty-three hundredths (0.33) of a foot below said grade line.

VIII. The trench lines referred to herein are the traces of the vertical planes between which the pipe is to be laid. They shall be assumed to be three (3) feet apart, that is, a trench-width of three (3) feet shall be assumed whatever the actual dimensions may be.

IX. The Contractor shall not (except after consent from the proper parties) enter or occupy with men, tools or material, any land outside the property of the Town.

CHAPTER XVII

TECHNICAL SPECIFICATIONS

Specifications must not only describe accurately and clearly the classes of materials, character of work and other features of the obligations assumed by the Contractor, but must present this information in such a way that it explains just what must be furnished by the Contractor for the price named under each item of his "bid or proposal." Some engineers prefer to include all excavation, bracing, bailing, pipe and specials, pipe laying and backfilling under a single item, obtaining a unit price per foot of completed sewer for each size of pipe; others prefer to buy their pipe and specials under a separate contract, and to pay the contractor for trench work in one item and pipe laying and jointing in another. Consequently the actual form of many parts of specifications intended to cover sewers of exactly similar character may vary widely on account of this difference of opinion regarding the best subdivision of the work for purposes of payment. Again, some engineers prefer to give a contractor a much wider range of choice in the methods of construction than other engineers consider advisable, and this difference of opinion is strongly shown in a comparison of some specifications for the same class of structures built under the same conditions.

The form of the authors' specifications is now based on the arrangement of the items in the "bid or proposal." In the case of the contract cited in Chapter XVI, for example, the items were: 1. Earth excavation; 2. rock excavation; 3. concrete masonry; 4. brick masonry, and so on. The specifications were arranged with the general clauses relating to the location and nature of the work, the inspection, the lines and grades and such matters, at the beginning, each of these clauses having a Roman number. The technical clauses came next, arranged in the order of the items in the bid. Under earth excavation, for example, there were 13 clauses, each of which was designated by a decimal number. The fact that a clause related to the first item was indicated by the number 1 preceding the decimal point, while the number 12 following the decimal point indicated that the clause was the twelfth relating to earth excavation. This arrangement and numbering is decidedly helpful in keeping the relations of the bid and the specifications clearly in view at all times. But such an arrangement is not necessarily the most convenient for a general study of the technical features of specifica-

tions, and in what follows each subject has accordingly been taken up as an independent article, with its clauses numbered consecutively.

The following general requirements for sewers are based primarily on the specifications prepared by the authors in collaboration with J. B. F. Breed, Chief Engineer of the Commissioners of Sewerage at Louisville, Ky., under which about 85 contracts were executed and about $3,300,000 spent, without any successful attack being made on them. As some of the contracts were taken at low unit prices, it is reasonable to assume that the stipulations were scrutinized minutely by numerous competent critics searching for every point of attack where there was any prospect of success. In addition to these Louisville specifications, the specifications prepared by E. J. Fort, Rudolph Hering and A. J. Provost, Jr., which were printed in the 1912 "Proceedings" of the American Society of Municipal Improvements, and the "Standard Specifications for Construction of Main and Branch Sewers" of the Philadelphia Bureau of Surveys have received special study, and the requirements of a number of cities regarding certain features have been obtained. It is believed that the following techical specifications reflect as well as practicable the present state of the art of American sewerage practice.

There are certain omissions which will be evident at once to the experienced engineer. One of these omissions is the absence of any cast-iron pipe specifications, which is due to the possible revision of the specifications of the New England Water Works Association and American Water Works Association for the purpose of bringing them into practically complete harmony. Neither are there any specifications for pavements laid over sewer trenches after the latter are filled, because such specifications have to be drawn in most cases to meet the local conditions of every street. The most important thing to specify is the thorough consolidation and rolling of the subgrade, so as to prevent any settlement of the backfilling after the pavement has been relaid. As the torn-up pavements are usually somewhat worn, it will be impracticable in most cases to replace them with a strip of pavement of the original height of the old work, as that would leave a ridge running along the roadway. The authors' experience leads them to believe that usually the safest way to avoid controversy is to require the contractor to "reconstruct" torn-up curbing and roadways in accordance with the drawings and the lines and grades given by the Engineer. To emphasize further that reconstruction is contemplated, the authors require the contractor to replace or replenish with new materials of similar kind and of a quality satisfactory to the Engineer all paving materials and curbing lost or damaged in handling or insufficient in quantity to complete the reconstruction of any block between adjacent streets. In case a new pavement is desired, the local specifications should be used if the Street Department so desires; otherwise the standard specifications of the American Society of Municipal Inprovements may be studied with profit.

The authors repeat that in some respects the following specifications are not those used in their own practice, but are believed to be representative of the general opinion of sewerage specialists in 1914, so far as it can be learned.

ART. I.—EXCAVATION

1. No trench shall be opened more than 200 ft. in advance of the completed sewer, without the written permission of the Engineer. Every trench in rock shall be fully opened at least 30 ft in advance of any place where masonry or pipe is being laid. In bad ground, such as running sand, the work shall be prosecuted vigorously night and day without interruption, when ordered by the Engineer. Trenches for house drains shall not be opened on both sides of the street at the same time unless permission has been previously obtained to close the street Unless otherwise directed, each trench for street inlet or catch-basin connections and house drains shall be excavated for its entire length within the street lines before any pipe are laid in it.

2. The "lines of excavation" of trenches in earth and rock for pipe sewers, connections with street inlets and catch-basins, and house drains, not over 18 in in diameter, shall be such as to give a clearance of at least 6 in on each side of the barrel of the pipe, and a clearance of at least 8 in. on each side of the barrel of the pipe when the latter has an inside diameter exceeding 18 in. All trenches shall have a clear width between "lines of excavation" equal to the maximum widths of the cradles of the sewers laid in them when such cradles are wider than the widths stated in the last preceding sentence. The "lines of excavation" of trenches in earth and rock for sewers other than pipe sewers shall be separated by a distance equal to the greatest external width of the structures to be built in them, including the necessary forms.

3. Trenches shall be excavated to the depths required for the foundations of the sewers and appurtenances shown on the drawings, and, where conditions make it necessary, to such additional depths as may be directed by the Engineer. In no case shall earth be plowed, scraped or dug by machinery nearer than 6 in to the finished subgrade; the last 6 in. shall be removed with pick and shovel just before placing the masonry.

4. Excavations directed to be made below the masonry, pipe or underdrain shall be refilled with gravel, broken stone or other approved material, spread in layers not more than 4 in. thick, and thoroughly moistened and tamped. The measurement of this refilling shall be in place in the work, and the price agreed upon under Item . . . shall include the cost of furnishing, placing and consolidating the material and all other work incidental to it.

5. The minimum dimensions of the excavation in earth for a manhole, catch-basin, receiving basin, riser, street inlet or other special structure shall be those of a prism with vertical sides and a horizontal section equal to the smallest section which will include such special structure and its foundations and, in the case of concrete structures, space not exceeding 6 in in width for the proper placing and removal of the necessary forms.

6. Rock, wherever used as the name of an excavated material, shall mean boulders exceeding 1/2 cu. yd. in volume or solid ledge rock which, in the opinion of the Engineer, requires for its removal drilling and blasting, or wedging, or sledging or barring. No soft or disintegrated rock which can be removed with a pick, no loose, shaken or previously blasted rock, no broken stone in rock fillings or elsewhere, and no rock which may fall into the trench from outside the limits of excavation shown on the drawings will be measured or allowed.

7. In rock the trench shall be carried 6 in. below the invert grade of a pipe sewer when no underdrain is required; if an underdrain is required the trench shall be carried to the depth and width required by the underdrain and gravel or broken stone refilling, as shown in the drawings. In the case of masonry sewers the rock shall be excavated to the depths required for the foundations and to a width 6 in. greater on each side than that of the masonry. The minimum dimensions of the excavation in rock for a manhole, catch-basin, flush-tank or other special structure shall be those of a prism with vertical sides and a horizontal section

6 in. wider on each side than the smallest rectangle which will enclose such structure and its foundation.

8. Rock shall be stripped in sections which, unless otherwise permitted, shall be not less than 50 ft. in length, and the Engineer shall then be notified in order that he may measure it. Rock blasted before such measurement is made will not be paid for.

9. Wherever a branch for a proposed sewer or extension of a sewer is built in rock, the required trench shall be excavated for a distance of not less than 5 ft. beyond the end of such branch, in the direction of the proposed sewer or extension.

10. All existing gas pipes, water pipes, steam pipes, electric conduits, sewers, drains, fire cisterns and hydrants, railway tracks and other structures which do not, in the opinion of the Engineer, require to be changed in location, shall be carefully supported and protected from injury by the Contractor, and in case of injury they shall be restored by him, without additional compensation, to as good condition as that in which they are found. Where pipes, conduits or sewers are removed from the trench, leaving dead ends in the ground, such ends shall be carefully plugged or bulkheaded with brick and mortar by the Contractor, without additional compensation.

11. Whenever it becomes necessary, in the opinion of the Engineer, to change the location of any sewer, drain or other structure, not otherwise provided for in these specifications, the Contractor shall do the whole of the work of making such changes, or such portions of it as the Engineer may direct, and the work will be paid for as extra work.

12. The Contractor shall provide without additional compensation suitable temporary channels for the water that may flow along or across the site of the work.

13. If the bottom of any excavation is taken out beyond the limits shown on the plans or prescribed by the Engineer, it shall be refilled at the Contractor's expense with concrete or other acceptable material in such manner as the Engineer may direct.

14. It is the intention to leave all paved surfaces over or adjacent to the sewer at the close of the work in good condition, and to that end the Contractor will be required to remove carefully and conserve free from any admixture of other materials all surfacing and paving materials and curbing disturbed, and to replace the same as directed in Article . . . . [This article should contain the local specifications, with any needed changes, for the classes of pavements used on the streets in which cuts are made; these requirements are so varied that even a summary of them would be out of place here] When the removed paving materials or curbing are lost, damaged or insufficient in quantity to complete the reconstruction of the pavement, they shall be replaced or supplemented with new materials of similar kind and of a quality satisfactory to the Engineer

15. Unless permission is given to the contrary, the material excavated from the trench and the materials of construction shall be so deposited and the work shall be so conducted as to leave open and free for pedestrian traffic all crosswalks, a space on each sidewalk not less than one-third of the width of the sidewalk and not less than 3 ft in width, and for vehicular traffic a roadway not less than 8 ft. in width. All street hydrants, water gates, fire alarm boxes and letter boxes shall be kept accessible for use. Not more than . . . lin. ft of sidewalk shall be used at any time for storage of materials from any one trench. During the progress of the work the Contractor shall maintain crosswalks, sidewalks, and roadways in satisfactory condition, and the work shall at all times be so conducted as to cause a minimum of inconvenience to public travel, and to permit safe and convenient access to private and public property along the line of the work.

16. Lawns on which excavated material is placed or walls which support it must be protected by planks or canvas.

17. If all excavated material cannot be stored on the street in such a manner as to maintain the traffic conditions specified in clause 15 of this article, the surplus shall be removed from the work and stored. After the construction of the sewer, so much of this material as is of satisfactory quality and necessary for the purpose shall be brought back and used for backfilling the trench.

18. When directed, in built-up districts and in streets where traffic conditions render it necessary, the material excavated from the first . . . ft. of trenches shall be removed by the Contractor as soon as excavated, and the material subsequently excavated, if suitable for the purpose, shall be used to backfill the trenches in which the sewers have been built, and neither the excavated material nor materials of construction shall be stored on the roadways or sidewalks.

19. When required by the Engineer, suitable fences shall be placed along the sides and ends of the trenches to keep the streets safe for traffic.

20. Tunneling will not be allowed without the approval of the Engineer, and the method of tunneling and the location of all shafts, portals and mechanical plant used in the tunneling operations shall also be subject to his approval. All tunnels shall be equipped with a sufficient number of lights to insure proper work and inspection. A supply of fresh air sufficient for the safety and efficiency of workmen and engineers shall be provided at all times throughout the length of any tunnel and especially at the headings. Additional lights and ventilation shall be supplied whenever directed by the Engineer. Headings are to be driven in both directions from the shafts, unless otherwise directed by the Engineer.

21. When earth excavation is paid for by the linear foot, the length to be paid for, whether in trench or tunnel (except where tunnel excavation is paid for under a special item) shall be the actual length in linear feet of the sewer constructed between the stations defining the limits of the portions included in the item for such excavation.

22. When earth excavation is paid for by the cubic yard, the quantity to be paid for shall be the number of cubic yards of material, exclusive of that paid for as rock excavation under Item . . ., that would have been removed if the excavation were everywhere in trench and exactly to the depth of the bottom of the masonry, or of the platform under the masonry, or of the barrel of the sewer pipe, and were carried to the "lines of excavation" shown on the drawings and defined in Clause 2 of this Article

23. When so designated, the excavation for special structures shall be paid for by the lump sum.

24. The prices agreed upon for earth and rock excavation and refill under Items . . . and . . . shall include the cost of all excavation and refilling, the removal of and delay or damage occasioned by any timber or masonry structures or other obstacles (whether shown on the drawings or not), the disposal of excavated material by removal or by refilling trenches (including rolling, ramming and watering this material where required), refilling in tunnel with concrete, sand or gravel; sheeting and bracing in open cut and in tunnel, timbering left in place in tunnel, bridging and fencing and removal of same, coffer damming, diking, pumping and bailing and other methods of disposing of water and sewage in or alongside the trench, protection and restoration of buildings, fences, existing conduits and pipes with their appurtenances, reconstruction of street pavements, sidewalks and grass plots, provision for the accommodation and protection of travel, and all other work incidental to the excavation, except that earth excavation and gravel refilling in trench below masonry, in accordance with Clause 4 of this Article, shall be included in and paid for under Items . . . and . . . .

25. The quantity of rock excavation to be paid for under Item . . ., shall be the number of cubic yards of ledge rock or boulders, in place as if measured before excavation, that would have been removed if the excavation had been made everywhere exactly to the depth of the bottom of the concrete masonry and to the limits stated in Clause 7 of this Article. The quantity of excavation in tunnel to be paid for under Items . . . and . . . shall be the earth or rock lying within the "lines of excavation" indicated on the drawings. Wherever deemed necessary by the Engineer and ordered in writing, additional rock excavation shall be performed and will be measured to the lines stipulated by the Engineer and paid for at the price stated in Item . . ..

ART. 2.—SHORING

1. The Contractor shall furnish, put in place and maintain such sheeting, bracing, etc., as may be required to support the sides and roof of the excavation and to prevent any movement which can in any way injure the masonry, diminish the necessary width of the excavation, or otherwise injure or delay the work or endanger adjacent pavements, buildings or other structures. If the Engineer is of the opinion that at any points, sufficient or proper supports have not been provided, he may order additional supports put in at the expense of the Contractor, and the compliance with such orders shall not release the Contractor from his responsibility for the sufficiency of such supports. Care shall be taken to prevent voids outside of the sheeting, but if voids are formed they shall be immediately filled and rammed to the satisfaction of the Engineer.

2. The Contractor shall leave in place to be imbedded in the backfill of the trench all sheeting, bracing, etc., not so shown on the plans which the Engineer may direct in writing to be left in place. The Engineer may direct that timber used for sheeting and bracing in trench be cut off at any specified elevation, in which case the Contractor shall be paid for an amount equivalent to what would have been left in the ground had the sheeting been cut off at an elevation 2 ft. higher, provided that this higher elevation does not carry into the next

higher set of sheeting, in which latter case payment *will be made only for the sheeting below the top of the set in which the cutting is made*

3. *For the purpose of preventing injury to persons, corporations or property, whether public or private, the liability for damages on account of which is to be assumed entirely and solely by the Contractor* under this contract, he may also leave in place to be imbedded in the backfill of the trench any and all sheeting, bracing, etc , in addition to that shown on the drawings or ordered in writing by the Engineer to be left in place, except that no sheeting and bracing which is within 4 ft. of the surface of the street may be left in place in the trench without written permission from the Engineer.

4. All sheeting and bracing which may not be left in place under the foregoing provisions of this agreement shall be removed in such manner as not to endanger the constructed sewer or other structures, utilities or property, whether public or private All voids left or caused by the withdrawal of sheeting shall be immediately refilled with sand, by ramming with tools specially adapted to that purpose, by watering or otherwise as may be directed.

5 All sheeting and bracing used in tunnel shall be left in place except when removed by permission of the Engineer.

6. The right of the Engineer to order sheeting and bracing left in place shall not be construed as creating any obligation on his part to issue such orders, and his failure to exercise his right to do so shall not relieve the Contractor from liability for damages to persons or property occurring from or upon the work of constructing the sewer occasioned by negligence or otherwise, growing out of a failure on the part of the Contractor to leave in place in the trench sufficient sheeting and bracing to prevent any caving or moving of the ground adjacent to the banks of the trench

7. For the sheeting and bracing which is shown upon the drawings to be left in place either in tunnel or in trench, the Contractor shall receive no payment, it being understood and agreed that his compensation therefor is included in the price to be paid for excavation and refill

For all timber used for sheeting, bracing and coffer damming actually left in the trench, which is not shown upon the plans to be left in place, but which shall be ordered by the Engineer in writing to be left in place to be imbedded in the backfill at any time during the progress of the work, the Contractor shall be paid the sum of $ . . . per thousand feet B M.; this does not include any timber in tunnel under Item . .

For all timber used for sheeting, bracing, etc , which is not shown upon the drawings to be left in place and which shall not be ordered by the Engineer in writing to be left in place during the progress of the work, but which shall be actually left in the trench for the convenience or to subserve the interests of the Contractor, the Contractor shall receive no payment, it being understood and agreed that his compensation therefor is included in the price to be paid for excavation and refill

For none of the sheeting, bracing, etc., which shall be removed from the trench nor for the cost of removing the same shall any payment be made, it being understood and agreed that the compensation therefor is included in the price to be paid for excavation and refill

ART. 3.—BLASTING

1. All blasting operations shall be conducted in strict accordance with existing ordinances and regulations relative to rock blasting and the storage and use of explosives. Any rock excavation within 5 ft of a water or gas main less than 36 in in diameter and within 10 ft. of a water or gas main 36 in or more in diameter shall be done with very light charges of explosive, and the utmost care shall be used to avoid disturbing the main.

2. All exposed sewers and special structures shall be carefully protected from the effects of blasts, and any damage done to them by blasting shall be promptly repaired by the Contractor at his own expense Sufficient warning shall be given to all persons in the vicinity of the work before blasting The site of the blast shall be covered with heavy timbers, blasting mats or other devices to prevent damage by flying rock. The time of blasting and the number and size of charges shall be satisfactory to the Engineer. The blasting shall be done only by experienced men.

3. Where there are no local ordinances governing blasting and the storage of explosives, all blasting supplies shall be stored in a manner approved by the Engineer, and a watchman shall be stationed at all times at the places of storage In no case shall caps or other exploders be kept at the place where dynamite or other explosive is stored.

ART. 4.—PUMPING, BAILING AND DRAINING

1. The Contractor shall remove by pumping, bailing or otherwise any water which may accumulate or be found in the trenches and other excavations made under this contract, and shall form all dams, flumes or other works necessary to keep them entirely clear of water while the sewers and their foundations, if any, are being constructed Newly laid masonry shall be protected from injury, resulting from the unwatering work and plant, by the use of canvas, tar paper or by such other sufficient methods, as may be approved. The Contractor shall at all times have upon the works sufficient pumping machinery ready for immediate use.

2 When directed by the Engineer, the Contractor shall lay a terra-cotta pipe with open joints, bedded in small gravel or stone crushed fine, in the trench below the foundation of the sewer for sub-soil drainage Unless otherwise ordered, this pipe shall be 5 in. in diameter; the laying of these underdrains shall be paid for at the prices named in Item . . .

3. Water from the trenches and excavations shall be disposed of in such a manner as will not cause injury to the public health nor to public or private property, nor to the work completed or in progress, nor to the surface of the streets, nor cause any interference with the use of the same by the public

4 Whenever so directed by the Engineer, the Contractor shall excavate a trench from either or both ends of the sewer to a natural water-course, whether the excavation be in earth or rock. The work shall be done in accordance with grades and dimensions furnished by the Engineer, and the Contractor shall be paid therefor at the prices stated in Items . . . and . .

ART. 5.—BACKFILLING

1 Unless otherwise directed, all trenches and excavations shall be backfilled as soon as the cement in the structures placed therein has acquired a suitable degree of hardness, and the work shall be prosecuted expeditiously after it has been commenced

2 For a depth of at least 2 ft over the top of sewers, basin connections, house connections and other drains, the material used for backfilling trenches shall be clean earth, sand or rock dust In the case of pipe sewers, the space between the pipe and the bottom and sides of the trench shall be packed full by hand and thoroughly tamped with a shovel or light tamper, as fast as placed, up to the level of the top of the pipe The filling shall be carried up evenly on both sides The pipe shall then be covered by hand to a depth of at least 2 ft. above its top, and at least one man engaged in tamping shall be provided for each man shoveling filling into the trench The material shall be deposited carefully in the trench to avoid injuring the sewer, and in case it is placed in layers these shall not exceed 6 in. in thickness and each shall be carefully and solidly tamped with appropriate tools in such a manner as to avoid injuring or disturbing the completed sewer In the case of masonry sewers the backfilling below an elevation 2 ft above the top of the sewer shall be deposited in layers not over 6 in. thick, each layer being leveled, wet if required, and thoroughly tamped before the next is placed, care being taken not to disturb or injure the sewer.

3. The remainder of the trench, above an elevation 2 ft. higher than the crown of the sewer, shall be backfilled with approved material free from organic matter, no layer to be more than 1 ft thick and each layer to be thoroughly tamped with rammers weighing not less than 20 lb before another is deposited. Where the trench is not in a paved street, at least one man tamping shall be provided for every two men shoveling. Where the trench is in a macadamized or paved street, the material shall be spread in layers not over 6 in thick, and thoroughly rammed, there being provided one man ramming for each man shoveling. Unless otherwise shown on the drawings, trenches shall be backfilled to the height of the surface of the ground as it existed at the commencement of the work Should there be a deficiency of proper material for the purpose, the contractor shall furnish and place such additional material as may be required

4. No heavy rock shall be dropped into the trench until there is at least 3 ft. of fill over the top of the sewer, and in depositing rock in the sewer, care must be taken that the rock does not injure the structure. All spaces between pieces of rock shall be filled with earth to insure there being no voids.

5. Where the backfilling can be compacted in a suitable manner by flooding or puddling with water, the Contractor will be permitted to do so, but he shall furnish the water at his own expense.

6. When sheeting is drawn, all cavities remaining in or adjoining the trench shall be solidly filled. When sheeting is left in place, all cavities behind such sheeting shall be solidly filled.

7. Backfilling within 2 ft. of manholes, catch-basins, flush-tanks and other special structures shall be of the same quality as that specified in Clause 2 of this section. It shall be uniformly deposited on all sides and, unless otherwise permitted, solidly tamped in such a manner as to avoid injuring the structures or producing unequal pressures on them.

8. Where the crown of the sewer comes close to the surface of the ground or extends above it, it shall be covered by an embankment at least 3 ft. thick over the top and sides of the sewer, with side slopes of at least 1 on 1-1/2 to the surface of the ground. Where such slopes would extend into or obstruct a natural water-course, street or private property, the Contractor shall retain the slopes by rubble masonry walls, and when ordered by the Engineer the sewer shall be covered to a depth of 6 in. with concrete and plastered with Portland cement mortar. All manholes are to be protected, if necessary, by an embankment at least 3 ft thick around the shaft to an elevation at least 3 ft above the top of the sewer.

ART. 6.—PILING

1 Piles to carry a platform or cradle shall be driven in all soft or marshy soil where directed by the Engineer or shown on the drawings They are to be driven to refusal, or as may be otherwise directed, with a hammer weighing at least 2000 lb , subject to the approval of the Engineer Refusal in general will be indicated by a penetration not exceeding 1 in.e pr blow under the last six blows of a 2000-lb. hammer falling 15 ft. If steam-hammer piledrivers are used, the piles shall be driven so that their bearing power shall be not less than that of piles driven as before specified A water jet may be used in pile driving, if authorized by the Engineer in writing The tops are to be sawed off truly at the required elevation. Where it is necessary to cut off the heads of the piles below water no extra compensation shall be made for such cutting The spaces around the piles and caps up to the under side of the planks of the platform shall be filled with good earth thoroughly rammed or puddled, unless otherwise directed. Pile heads imbedded in concrete shall have the bark removed from the surface of contact

2. All piles shall be straight, sound yellow pine or.. ......, not less than 6 in. in diameter at the small ends and not less than the diameters shown in the accompanying Table of Minimum Cut-off Diameters, where cut off, or of other dimensions shown on the drawings, hooped and shod if required All dimensions are to be measured exclusive of the bark. The point of each pile shall be trimmed to a 4-in square end at right angles to the axis of the pile, unless otherwise directed.

TABLE OF MINIMUM CUT-OFF DIAMETERS FOR PILES OF DIFFERENT LENGTHS BELOW CUT-OFF

Length, feet	[1]20	20-25	25–35	36–45	[2]46
Diameter, inches	10	11	12	13	14

3. Piles that do not bring up satisfactorily, or are too short, or are out of line must be replaced by others of length and alignment satisfactory to the Engineer. Piles badly split in driving shall either be replaced with others or repaired with wrought iron rings or screw bolts, as may be directed. When the Engineer considers that a pile head has become so broomed as to be unfit for further driving, the broomed portion shall be sawed or adzed off before the driving is continued. The heads of all piles must be protected against damage by the blows of the hammer, by wrought iron rings. Piles shall be driven without the use of a follower unless specially permitted.

4. Where shown on the drawings, brace, batter, or spur piles shall be driven at the inclinations shown or directed, and the tops shall be framed, bolted or strapped to adjoining piles or to each other, as shown on the drawings.

5. The amount of piles to be paid for will be the total length below the cutoff of all piles remaining in the works in accordance with the drawings or directions, and the total length

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[1] The cut-off diameter of piles less than 20 ft. shall be at least 10 in.

[2] 14 in. is the maximum size required at the cut-off of any pile.

of all piles used only as test piles. Piles driven for temporary use will not be paid for. The contract price for piles shall cover the cost of all labor and materials required to furnish, drive and cut off the same as specified, of fastening brace piles, and of furnishing and placing all shoes, bands, bars, straps, bolts and other fastenings required.

6. Concrete piles satisfactory to the Engineer may be required under certain portions of the work, and when ordered by the Engineer in writing they shall be placed in the positions and in the manner directed by him. The contractor shall furnish all labor and materials and provide and use such machinery as may be necessary to do this work to the satisfaction of the Engineer, and he will be paid for the same as extra work, under Item 17.

ART. 7.—FOUNDATIONS

1. Where piles cannot be driven more than 7 ft. below the cut-off, a platform only may be required; or masonry foundations, without a platform, extending to a suitable bottom shall be substituted if directed by the Engineer. The word "platform" shall be understood to include both capping and planking.

2. All timber and planking for foundations shall be of good quality sawed, long-leaf yellow pine or ...., straight, sound, free from shakes, large, loose or decayed knots and other imperfections impairing its strength and durability. All sizes under 9 in. shall show some heart the entire length of one side and sizes of 9 in. or more shall show some heart the entire length of two opposite sides. Wane may be allowed one-eight of the width of the piece, measured across the face of wane, and extending one-fourth of the length of the piece on one corner, or its equivalent on two or more corners, provided that not more than 10 per cent. of the pieces of any one size show such wane.

3. The caps shall be 8 × 8-in. timber unless otherwise directed. The planks shall generally be 18 ft. long and at least 8 in. wide; the joints are to be broken at least 6 ft. and must be on caps. Holes shall be bored for the spikes. The spikes are to be wrought iron or steel wharf spikes, square in section and of a length at least twice the thickness of the timber through which they are to be driven. Spikes 8 to 12 in. long, inclusive, are to be 1/2 in. square; 14 and 16 in. long, 5/8 in. square; 18 in. long, 3/4 in. square, 20 and 22 in. long, 7/8 in. square; 24 in long, 1 in square.

4. Platform laid directly on the ground shall have a smooth, firm bearing throughout.

ART. 8.—CEMENT

1. All cement shall be dry Portland cement free from lumps; it shall be the finely pulverised product resulting from calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials to which no addition greater than 3 per cent. has been made subsequent to calcination.

2. It shall be delivered in strong cloth or canvas bags containing 94 lb. net or in sound, paper-lined barrels containing 376 lb. net. Each package shall be clearly marked with the brand and manufacturer's name.

3. The Contractor shall submit the cement and afford every facility for inspection and testing, at least 12 days before desiring to use it, and the Engineer shall be notified at once of the receipt of each shipment at the work.

4. The cement shall be protected in a suitable building having a wooden floor raised above the ground or be placed on a wooden platform and properly protected with canvas. Each shipment shall be stored separately and each lot marked with an indentification number and the date of receipt.

5. The failure of a shipment of cement on any work to meet the requirements of the specifications shall justify the prohibition of further use of the same brand on that work. Cement may be inspected either at the place of manufacture or on the work. Cement failing to meet the 7-day requirements may be held awaiting the results of the 28-day tests before rejection. All tests shall be made in accordance with the methods recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to that society on January 21, 1903, with all subsequent amendments. The acceptance or rejection of the cement shall be based on the following requirements: [These are the technical requirements in the standard specifications for Portland cement adopted by the American Society for Testing Materials on Aug. 16, 1909.]

6. The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

7. It shall leave by weight a residue of not more than 8 per cent. on the No. 100, and not more than 25 per cent on the No 200 sieve

8. It shall not develop initial set in less than 30 minutes; and must develop hard set in not less than 1 hour nor more than 10 hours

9. The minimum requirements for tensile strength for briquettes 1 sq in. in cross-section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

Age	Strength
Neat Cement	
24 hours in moist air	175 lb.
7 days (1 day in moist air, 6 days in water)	500 lb.
28 days (1 day in moist air, 27 days in water)	600 lb.
One Part Cement, Three Parts Standard Ottawa Sand	
7 days (1 day in moist air, 6 days in water)	200 lb.
28 days (1 day in moist air, 27 days in water)	275 lb.

10. Pats of neat cement about 3 in in diameter, 1/2 in thick at the center and tapering to a thin edge, shall be kept in moist air for a period of 24 hours. (*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days (*b*) Another pat is kept in water maintained as near 70° F as practicable, and observed at intervals for at least 28 days (*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hours

11. These pats, to pass the requirements satisfactorily, shall remain firm and hard, and show no signs of distortion, checking, cracking, or disintegrating

12 The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

ART. 9.—SAND, GRAVEL AND BROKEN STONE

1. The sand shall be clean and sharp, free from dirt, loam, mica and organic matter, and shall contain not more than 8 per cent by volume of clay, and no clay shall be artificially added. On the 7-day test the sand shall be of such a quality that the tensile strength of the briquettes made in the laboratory, of 1 part of cement and 3 parts of sand, shall not be less than 65 per cent. of the strength of similar briquettes made of the same material and Ottawa sand.

2. Gravel shall be composed of clean, hard stone, free from dirt, loam, mica, clay and organic matter, and unless otherwise ordered in writing by the Engineer, shall be separated by screening into the sizes specified for broken stone in Clause 3 of this Article

3. Broken stone for concrete shall be hard, sound and durable, and shall not contain loam, clay, organic matter or objectionable quantities of dust or other materials considered undesirable by the Engineer The broken stone shall be separated into three grades by means of a screen with circular openings 1, 1-1/2, and 2 in. in diameter and a screen with openings 1/4 in. in diameter, which last-mentioned diameter is that of the smallest pieces of stone which will be accepted.

4. If permitted in writing by the Engineer, gravel and broken stone may be mixed The purpose of grading the gravel and broken stone into three sizes is to enable a mixture to be produced from them which, in the opinion of the Engineer, will make the most suitable concrete. The material shall be washed, if ordered by the Engineer, and the Contractor shall maintain an acceptable plant with adequate storage facilities for the different grades of gravel, broken stone, or both, so that they may be combined readily in the proportions designated by the Engineer.

5. Samples of sand, gravel and broken stone which the Contractor proposes to use shall be submitted to the Engineer, if so required by him, for examination at least two weeks before the Contractor commences to deliver the materials at the site of the works. Materials shall not be delivered until the samples shall have been approved, and as delivered they shall in all respects be equal to the approved samples. Samples of sand, of about 1 quart, shall

be submitted in glass jars with stoppers and samples of not less than 1 cu. ft. of gravel or of broken stone in suitable boxes or other receptacles. All samples shall be plainly labeled with the name of the place from which they were taken, where it is proposed to use them, and the name of the collector and date of collection.

6. In these specifications the word "Ballast" signifies the mixture of graded sizes of gravel, broken stone or both which is designated for use by the Engineer.

ART. 10.—MORTAR

1. All mortar, unless otherwise specified, shall be composed of 1 volume of cement and 2 volumes of sand. Mortar used in the haunch walls of brick sewers shall be composed of 1 volume of cement and 3 volumes of sand. For purposes of measurement a barrel of cement shall be considered to contain 3.8 cu. ft. and a bag of cement 0.95 cu. ft.

2. The water used in preparing mortar shall be clean and free from sewage. Salt water shall be used as directed by the Engineer when it is necessary to construct masonry in freezing weather.

3. The ingredients shall first be thoroughly mixed dry in a suitable tight box, after which the proper quantity of clean water shall be gradually added and then the materials shall be hoed or worked until a uniform mixture is secured. No greater quantity of mortar is to be prepared than is required for immediate use and it shall be worked over constantly with hoe or shovel until used, any that has set shall not be retempered or used in any way, and no mortar shall be used more than 1 1/2 hours after mixing.

4. Mortar taken from the mixing troughs and molded into briquettes 1 in. square in cross-section shall have an ultimate tensile strength of 125 lb. per square inch after one day in the air and six days in water, and 175 lb. after one day in air and 27 days in water.

ART. 11.—BILLET-STEEL CONCRETE REINFORCEMENT BARS

[Adopted by the American Society for Testing Materials on August 25, 1913, and reprinted by permission. Slight modifications have been made to fit the requirements to the conditions existing on sewerage contracts.]

1. (*a*) These specifications cover three classes of billet-steel concrete reinforcement bars, namely, plain, deformed and cold-twisted, and the classes to be furnished under this contract are those whose prices are stipulated in Item . . . . (*b*) Plain and deformed bars are of two grades, namely, structural steel and hard.

2. (*a*) The hard grade will be used only when specified. (*b*) If desired cold-twisted bars may be purchased on the basis of tests of hot-rolled bars before twisting, in which case such tests shall govern and shall conform to the requirements specified for plain bars of structural steel grade.

3. (*a*) The steel may be made by the Bessemer or the open-hearth process: (*b*) The bars shall be rolled from new billets; no rerolled material will be accepted.

4. Cold-twisted bars shall be twisted cold with one complete twist in a length not over 12 times the thickness of the bar.

5. The steel shall conform to the following requirements as to chemical composition:

Phosphorus	Bessemer . .	not over 0.10 per cent.
	Open-hearth . .	not over 0.05 per cent.

6. An analysis to determine the percentage of carbon, manganese, phosphorous and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Clause 5 of this Article.

7. Analyses may be made by the purchaser from finished bars representing each melt of open-hearth steel, and each melt or lot of 10 tons of Bessemer steel, in which case an excess of 25 per cent. above the requirements specified in Clause 5 shall be allowed.

8. (*a*) The bars shall conform to the requirements stated in the accompanying Table of Tensile Properties:

TABLE OF TENSILE PROPERTIES REQUIRED IN BARS

Properties considered	Plain bars		Deformed bars		Cold-twisted bars
	Structural steel grade	Hard grade	Structural steel grade	Hard grade	
Tensile strength, lb per sq. in	55,000-70,000	80,000 Minimum	55,000-70,000	80,000 Minimum	Recorded only
Yield point, min , lb per sq. in . .	33,000	50,000	33,000	50,000	55,000
Elongation in 8 in , min., per cent .	1,400,000[1] / Tens. str.	1,200,000[1] / Tens. str	1,250,000[1] / Tens. str.	1,000,000[1] / Tens. str.	5

[1] See Clause 9.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

9. (*a*) For plain and deformed bars over 3/4 in in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Clause 8 (*a*), shall be made for each increase of 1/8 in in thickness or diameter above 3/4 in. (*b*) For plain and deformed bars under 7/16 in. in thickness or diameter a deduction of 1 from the percentages of elongation specified in Section 8 (*a*), shall be made for each decrease of 1/16 in in thickness or diameter below 7/16 in.

10. The test specimen shall bend cold around a pin without cracking on the outside of the bent portion, as stated in the accompanying Table of Bend Test Requirements.

TABLE OF BEND TEST REQUIREMENTS

Thickness or diameter of bar	Plain bars		Deformed bars		Cold-twisted bars
	Structural steel grade	Hard grade	Structural steel grade	High grade	
Under ¾ in	180 deg. $d = t$	180 deg $d = 3t$	180 deg. $d = t$	180 deg. $d = 4t$	180 deg. $d = 2t$
¾ in or over	180 deg. $d = t$	90 deg. $d = 3t$	90 deg $d = 2t$	90 deg $d = 4t$	180 deg. $d = 3t$

Explanatory Note. d = the diameter of pin about which the specimen is bent.
t = the thickness or diameter of the specimen.

11. (*a*) Tension and bend test specimens for plain and deformed bars shall be taken from the finished bars, and shall be of the full thickness or diameter of material as rolled, except that the specimens for deformed bars may be machined for a length of at least 9 in., if deemed necessary by the manufacturer to obtain uniform cross-section. (*b*) Tension and bend test specimens for cold-twisted bars shall be taken from the finished bars, without further treatment, except as specified in Clause 2 (*b*) of this Article.

12. (*a*) One tension and one bend test shall be made from each melt of open-hearth steel and from each melt or lot of 10 tons of Bessemer steel; except that if material from one melt differs 3/8 in. or more in thickness or diameter one tension and one bend test shall be made for both the thickest and the thinnest material rolled. (*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted.

13. The weight of any lot of bars shall not vary more than 5 per cent. from the theoretical weight of that lot.

14. A finished bar shall be free from injurious defects and shall have a workmanlike finish.

15. The Inspector representing the Purchaser shall have free entry, at all times while work on the contract of the Purchaser is being performed, to all parts of the Manufacturer's works which concern the manufacture of the bars ordered. The Manufacturer shall afford the Inspector, free of cost, all reasonable facilities to satisfy him that the bars are being fur-

nished in accordance with the specifications. All tests (except the check analyses) and inspections shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

16. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Clause 7 of this Article shall be reported within five working days from the receipt of sample. (*b*) Bars which show injurious defects subsequent to their acceptance at the Manufacturer's works will be rejected, and the Manufacturer shall be notified.

17. Samples tested in accordance with Clause 7 of this Article, which represent rejected bars, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the Manufacturer may make claim for a rehearing within that time.

ART. 12.—RAIL-STEEL CONCRETE REINFORCEMENT BARS

[Adopted by the American Society for Testing Materials on August 25, 1913, and reprinted by permission. Slight modifications have been made to fit the requirements to the conditions existing on sewerage contracts.]

1. These specifications cover three classes of rail-steel concrete reinforcement bars, namely, plain, deformed, and hot-twisted, and the classes to be furnished under this contract are those whose prices are stipulated in Item . . . .

2 The bars shall be rolled from standard-section Tee rails.

3 Hot-twisted bars shall have one complete twist in a length not over 12 times the thickness of the bar.

4 (*a*) The bars shall conform to the accompanying Table of Minimum Required Tensile Properties.

TABLE OF MINIMUM REQUIRED TENSILE PROPERTIES

Properties considered	Plain bars	Deformed and hot-twisted bars
Tensile strength, lb per sq in	80,000	80,000
Yield point, lb per sq in	50,000	50,000
Elongation in 8 in, per cent	$\frac{1{,}200{,}000}{\text{Tens. str.}}$[1]	$\frac{1{,}000{,}000}{\text{Tens. str.}}$[1]

[1] See Clause 5.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

5. (*a*) For bars over 3/4 in in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Clause 4 (*a*) shall be made for each increase of 1/8 in. in thickness or diameter above 3/4 in (*b*) For bars under 7/16 in in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Clause 4 (*a*) shall be made for each decrease of 1/16 in in thickness or diameter below 7/16 in

6 The test specimen shall bend cold around a pin without cracking on the outside of the bent portion, as stated in the accompanying Table of Bend Test Requirements:

TABLE OF BEND TEST REQUIREMENTS FOR RAIL-STEEL BARS

Thickness or diameter of bar	Plain bars	Deformed and hot-twisted bars
Under ¾ in.	180 deg. $d = 3t$	180 deg. $d = 4t$
¾ in. or over	90 deg. $d = 3t$	90 deg. $d = 4t$

Explanatory Note: d = the diameter of pin about which the specimen is bent.
t = the thickness or diameter of the specimen.

7. (*a*) Tension and bend test specimens for plain and deformed bars shall be taken from the finished bars, and shall be the full thickness or diameter of bars as rolled; except that the specimens for deformed bars may be machined for a length of at least 9 in., if deemed necessary by the Manufacturer to obtain uniform cross-section. (*b*) Tension and bend test specimens for hot-twisted bars shall be taken from the finished bars, without further treatment.

8. (*a*) One tension and one bend test shall be made from each lot of 10 tons or less of each size of bar rolled from rails varying not more than 10 lb per yard in nominal weight (*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted

9. The weight of any lot of bars shall not vary more than 5 per cent from the theoretical weight of that lot

10. The finished bars shall be free from injurious defects and shall have a workmanlike finish.

11. The inspector representing the Purchaser shall have free entry, at all times while the work of the contract with the Purchaser is being performed, to all parts of the Manufacturer's works which concern the manufacture of the bars ordered The Manufacturer shall afford the Inspector, free of cost, all reasonable facilities to satisfy him that the bars are being furnished in accordance with these specifications All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works

12 Bars which show injurious defects subsequent to their acceptance at the Manufacturer's works will be rejected, and the Manufacturer shall be notified.

ART. 13.—IRON CASTINGS

1. All castings required in the execution of this contract shall be made by the cupola process, unless furnace iron is specified.

2. The castings shall be known as "light" when they have any section less than 1/2 in. thick, "heavy" when no section is less than 2 in thick, and "medium" when they are in neither the light nor heavy class

3. The metal of the castings shall meet the requirements of the accompanying Table of Required Qualities of Gray-iron Castings

Table of Required Qualities of Gray-iron Castings

Quality or property	Light castings	Medium castings	Heavy castings
Maximum sulphur content, per cent	0.08	0.10	0.12
Minimum breaking strength of Arbitration Bar[1] under transverse load, lb	2,500	2,900	3,300
Minimum deflection of Arbitration Bar, in	0.10	0.10	0.10
Minimum tensile strength, lb per sq in	18,000	21,000	24,000

[1] The Arbitration Bar is 1-1/4 in. in diameter and 15 in. long, and is placed on supports 12 in. apart and loaded in the middle at a rate which will produce a deflection of 0.10 in. in 20 to 40 seconds. Two sets of two bars each are cast from each 20 tons of a heat.

4. Castings shall be true to pattern, free from cracks, flaws and excessive shrinkage. They shall have their faces machined to true surfaces wherever required on the drawings. They shall be thoroughly cleaned and then painted with .... or approved substitute.

ART. 14.—BRICK MASONRY

1. None but whole, sound, thoroughly burned, straight, hard brick, uniform in structure with true, even faces, shall be used. All brick shall meet such requirements as to specific gravity, absorption, abrasion and crushing strength as the Engineer shall deem necessary.

[This sentence is based on the Philadelphia general specifications and should be adopted only where the quality of acceptable brick is known to contractors through experience in the city under the same engineer; otherwise it is better to state in the specifications just what properties the brick must possess] Hard-burned brick, less perfect than those required for the sewer, and half brick, all satisfactory to the Engineer, may be used in the manholes All brick shall be sorted, when delivered upon the ground, by men furnished to the Inspector by and at the expense of the Contractor, and all brick condemned shall be immediately removed from the work.

2. Vitrified shale brick shall be tough, homogeneous, of a compact structure, and burned uniformly throughout They shall be free from laminations, fire cracks or checking of more than a superficial character, free from lime or other soluble matter, and shall show no signs of spalling or pitting after three days' immersion in water

3. The Contractor shall furnish to the Engineer at least six samples of the brick which he wishes to use in the work, at least one month before delivery of material on the ground These samples shall be subjected to such tests as the Engineer shall designate under Clause 1 of this Article

4 All brick shall be thoroughly wetted immediately before being laid, either by immersion or in such other manner as is acceptable to the Engineer Old brickwork shall be cleaned and wetted before laying new work on it

5. Every brick is required to be laid in a full and close joint of Portland cement mortar composed of 1 part cement and 2 parts sand, on its bed, end and side at one operation The joints on the inside face of work shall not exceed 1/4 in in thickness and in no case shall mortar be slushed in afterward Care shall be taken to have every joint full of mortar Upon removal of the centers, if any open joints are found they shall be pointed Special care shall be taken to make the face of the brickwork smooth, and all joints on the interior surface of the invert of the sewer shall be carefully struck with the point of the trowel, or pointed to the entire satisfaction of the Engineer The work in all cases shall be well and thoroughly bonded, and if the manner is specified or shown on the drawings it shall be done in close adherence to them. Brickwork as it progresses may be toothed, but when ordered it shall be racked back in courses.

6 All inverts or bottom curves shall be worked from templets, accurately made according to the dimensions of the sewer, and correctly set according to lines and grades furnished. When specified upon the drawings or schedules, the invert of sewers shall be of granite or trap rock blocks, as specified under Stone Masonry, Article 15, Clause 9, or of vitrified shale brick as specified in Clause 2 of this Article, to the height shown upon the drawings

7. The extrados of the arch shall be neatly plastered, at least 1/2 in thick, with mortar of the same quality as that used in the brickwork

8. The centers upon which the arches are formed shall be made strong, and according to the sizes and shapes required, arches on curves shall be constructed on centers of proper curvature No center shall be removed until the work upon it has set and the refilling has progressed up to the crown of the arch, if so ordered All centers shall be struck and drawn with care, so as not to crack and injure the work

9. All fresh work shall be protected from injury Newly laid inverts shall be protected from wash by canvas covering or tar paper, and should the regular continuity of the arch or invert be destroyed at any time, either from irregular settlement or from the centers being improperly fixed, or from any other cause, the Contractor shall remove such portions and correct the irregularity in a satisfactory manner All new work, unless immediately covered with earth, shall be kept moist until the mortar has become hard and will not crack in the sun.

10. The quantity of brick masonry to be paid for in Item ... shall be determined by measurement or by estimate of the number of cubic yards actually built, as required by the drawings and directions furnished from time to time by the Engineer. The price agreed upon shall include the furnishing of brick, cement, sand, templets and centers, and all work, including the setting of inlets, necessary for the building of brick masonry.

ART. 15.—STONE MASONRY

1. All stones shall be of good quality, hard, clean, of good bed and build, and not less than 6 in. thick, unless for trimming or closing. Each stone shall have a firm and solid

bearing, and be laid on its broadest bed, in full bed of fresh 1 : 2 Portland cement mortar, with which all joints shall be thoroughly filled.

2. Stone masonry shall be laid true and by line, and built of the exact dimensions and character shown on the drawings It shall be well and thoroughly bonded, and the courses shall be roughly leveled up. When the laying of rubble masonry in mortar is interrupted, the tops of the courses shall be left unplastered. No dressing or tooling shall be done on or upon any stone after it is in place. No rubble masonry laid in mortar shall be constructed in freezing weather.

3. When the faces of rubble masonry laid in mortar will be exposed to view in the finished work, the joints in such faces shall be raked out to a depth of not less than 1 in. and neatly pointed with mortar The tops of walls where other finish is not required shall be plastered and floated to a smooth finish.

4. No masonry shall be built on concrete before it is thoroughly set.

5. Before building upon old masonry, its surface shall be cleaned of old mortar and dirt and thoroughly wetted; stones removed from the old work and allowed to be used shall be similarly treated

6. The face stones shall be well scabbled and closely set Unless otherwise directed they shall be two-man stones, they shall be bonded so that there are about twice as many stretchers as headers When rubble masonry is built as cradling and foundations for brick arches, it shall consist of one- and two-man stones unless a larger size is called for on the drawings.

7. In dry walls without mortar, one- and two-man stones shall be generally used Each shall be laid by hand, settled with hammer, and have a fair and even bearing; all joints and crevices shall be thorougly pinned and wedged, and the courses well bonded. Riprap shall be laid by hand, or if a great quantity is furnished it shall be dumped in place, as directed

8. Coping stones shall be sound stones of approved kind and quality, as indicated on the drawings. The shapes and dimensions given shall be truly adhered to, and they shall be dressed and hammered in a manner and after the pattern required by the drawings, with a smooth top surface and a close joint They shall be well and truly laid to line and grade

9. Where stone block invert is required it shall consist of granite or trap rock blocks, with true square heads and sides not warped, 6 to 7 in deep, 10 to 14 in long, 3-1/2 to 5 in wide They shall be sorted at the quarries and delivered in uniform sizes. They shall be truly rectangular and free from irregularities exceeding 1/4 in Blocks of equal width shall be laid in a continuous course. Worn paving blocks shall not be used.

ART. 16.—CONCRETE, PLAIN AND REINFORCED

1. Unless otherwise specified on the drawings or directed by the Engineer the concrete shall be composed of one volume of cement and seven volumes of such mixture of sand and ballast as shall be required by the Engineer. If the sand and ballast are stored in piles at any time, they shall be placed on a platform or other hard, clean surface, to avoid any admixture of dirt with them

2. Cement, sand and ballast, shall be measured (not estimated) in the given proportions, and mixed in a proper box, or on a floor, and in no case on the ground. Mixing of materials shall be done thoroughly by machine wherever practicable, and always in batches When mixed by hand, the cement and sand shall be first thoroughly mixed dry until the color of the material is uniform in tint, and then made into a soft mortar by gradually adding clean water and hoeing or otherwise working until a uniform homogeneous mixture is obtained. The stone shall be spread upon a suitable floor to a depth of about 6 in. and thoroughly wetted, and the mortar spread evenly over it. The whole mass shall then be turned with square-end shovels until it shall become mixed to the satisfaction of the Engineer. The concrete shall be kept in motion until deposited in place; should any be permitted to set before it is placed and tamped, it shall be removed and not used again Hand-mixed batches shall not be larger than 1 cu. yd. in volume. The concrete shall not be mixed in larger quantity than is required for immediate use.

3. When sewers are built of concrete or reinforced concrete, the longitudinal sections of the side walls shall be constructed without interruption from bottom to top, and each longitudinal section of the roof or arch shall be constructed its full thickness without interruption, so as to form a monolith in each case, the length of each section to be such as to permit completing it within the working hours of a day.

4. The concrete shall be deposited in layers of the thickness required, and shall be thoroughly compacted by working it with a straight shovel or slicing tool, kept moving up and down until all the ingredients have settled into their place by gravity and the surplus water has been forced to the surface. The concrete shall be thoroughly worked about pipes, reinforcing bars and other metal work, so as to obtain a complete bond everywhere on the surfaces of contact between the metal and concrete. Care shall be taken to keep the forms moist and to work the materials well with shovels or other tools in the spaces between the forms, so as to obtain smooth surfaces. When a fresh layer of concrete is to be put on one which has set or partly set, the surface shall be roughened, thoroughly cleansed of foreign material and laitance, using a stiff wire brush and a stream of water, if required, and shall then be slushed with a mortar consisting of 1 part Portland cement and 2 parts of sand When the placing of concrete is suspended, all necessary grooves for joining future work shall be made before the concrete has had time to set. Expansion joints of the type indicated on the drawings or as directed shall be constructed wherever ordered by the Engineer, and only at such places as the Engineer may approve.

5. No concrete shall be laid in water, nor shall water be permitted to rise on it within 24 hours after it is placed, nor shall water be allowed to run over completed masonry before 4 days. No wheeling, walking or working on finished surfaces will be allowed for 24 hours after they are completed. Immediately after the face forms are removed, which shall be before the concrete has completely hardened, if practicable, the surface shall be freed from inequalities and projections. All voids shall be filled by floating with cement mortar, and the entire surface shall be brushed or broomed with a thin wash composed of equal parts of cement and fine sand. Unsatisfactory concrete shall be taken down and replaced, if directed by the Engineer.

6. Except during the colder months, the Contractor shall keep all concrete masonry wet by sprinkling with water or covering with wet cloths, until it shall have become thoroughly set and hard enough to prevent its drying and cracking. Sufficient tarpaulin or other covering shall be provided to protect fresh work from the action of the elements.

7. The Contractor shall furnish on the site of the work a sufficient number of centers, forms, molds, or templates for its expeditious prosecution. The forms shall be made in such a way and of such material as will insure a true and very smooth surface on the finished concrete. The design of the forms shall be submitted to the Engineer for approval before work on them is commenced The Engineer shall, at all reasonable times, have access to the shop or other place where the centers and forms are being made, and shall be furnished with every facility for inspecting them, and materials, centers and forms rejected by him shall not be used on the work The inspection of forms by the Engineer during or after the process of construction, or any suggestion or assistance furnished by the Engineer, shall not be construed as relieving the Contractor of the entire or any part of the responsibility for the accuracy or sufficiency of any of the forms or for the satisfactory completion of the masonry to any extent dependent thereon

8. The centers and forms of all surfaces shall be carefully cleaned and prepared or covered in a satisfactory manner, so that they may be readily removed and leave the concrete with a smooth presentable surface All centers and forms shall be substantially water-tight and of sufficient strength and so well placed that they will maintain their proper place and position during the placing and ramming of the concrete No center or form shall be used which is not clean, of approved shape and strength, and in every way suitable. Deformed, broken or defective centers or forms shall be removed from the work. Care shall be taken to prevent shavings, sawdust and other wastes from the making of wooden forms and centers from becoming imbedded in the masonry.

9. Forms and centers shall be left in place until the concrete has set sufficiently to permit their removal without danger to the structure, and until so much of the backfilling or embankment as may be directed has been put in place. Unless otherwise ordered, no center shall be struck until the backfilling over it has been completed to the elevation of a horizontal plane 2 ft. above the top of the completed masonry. In no case shall forms or centers be struck or removed until permission to do so has been given by the Engineer.

10. Rubble concrete shall consist of concrete of the proportions stated in Clause 1 of this article, with large stones imbedded therein. The imbedded stones shall be hard, sound and firm, roughly cubical in shape if practicable, and of such sizes as may be deemed suitable for the mass in which they are to be used. They shall be laid on their largest sides and be so placed in the work that they will not be nearer than 9 in. to the bottom of a footing, to an

expansion joint, or to any surface or to each other The stones, after having been thoroughly cleaned and wetted, shall be firmly bedded in the concrete The joints shall then be filled and the stones covered with concrete to such a depth that the spacings specified will be obtained The stones shall not be placed directly on any concrete which has acquired its initial set

11. Where a granolithic mixture is to be used it shall be composed of one part cement, one part sand or gravel, and 1½ parts granolithic grit, by volume, and the necessary amount of water to make a thick mortar This shall be deposited by skilled workmen in a manner satisfactory to the Engineer, as the work progresses Where granolithic finish is specified on horizontal surfaces of sewers, the mixture shall be deposited on top of the concrete to a thickness of at least 1½ in, immediately after the latter has been rammed and before it has set, so as to be incorporated into and form part of the main mass of the concrete The upper surface shall be brought to the required shape, dimensions and grades shown on the drawings, by means of screeds, and floated and troweled to a smooth surface, free from all stones A drier mix in the proportions of 1 part sand and 2 parts cement, by volume, shall then be sprinkled in a dry state over the surface, and be floated and troweled This treatment shall be repeated three times On all other exposed surfaces of sewers, the mixture shall be deposited against the face forms, with a thickness of at least 1 in., as the placing of the concrete proceeds, and thus be built into and form part of the body of the concrete

12. Steel bars for reinforcing concrete shall be of such shape as to afford an approved mechanical bond with the concrete, and to insure intimate contact between the steel and concrete Plain bars may be used only as shown on the plans Reinforcement bars will be rejected if the actual weight varies more than 5 per cent from the theoretical weight as shown by the manufacturer's tables All bars must conform to the requirements given in Article 11 They shall be protected at all times before being placed in the concrete from mechanical injury and from the weather, and when placed in the work they shall be free from dirt, scale, loose or scaly rust, paint and oil Bars which are to be imbedded in concrete but which remain exposed for some time after being placed in the work, shall, if directed, be immediately coated with a thin grout of equal parts of cement and sand

13 Bars shall be bent to the shape shown on the drawings, and in conformity with approved templets When bars are cut and bent on the work, the Contractor shall employ competent men and provide the necessary appliances for the purpose

14. All bars shall be as long as can be conveniently used, accurately bent, placed, spaced and jointed as shown on the drawings or directed, and shall be securely held in their position by approved devices until the concrete has been placed around them Where more than one bar is necessary to complete a required length, they shall be fastened together by approved clamps which will develop the full strength of the bars, or by linking the ends of the bars around each other in such a manner as to produce and maintain tension on the joints during construction, or by lapping the ends of the bars, as directed, and wiring them together in an approved manner, or the ends of the bars shall be lapped for a distance of 30 times their nominal diameter, for deformed bars, and 50 times their nominal diameters, for plain bars, and with a space not less than 2 in between them Joints in longitudinal bars shall be staggered as directed

15. The price bid in Item , for steel reinforcing bars shall include the cost of all labor and material where required to furnish, clean, cut, bend, place, join, secure and protect the same, and to furnish all test pieces and samples The weight of steel reinforcement bars paid for as such will be the weight computed from the lengths and theoretical net sections of the steel reinforcement bars placed in the work in accordance with the drawings or directions, except such steel reinforcement bars shown on the drawings as part of structures for which there are contract prices.

16. The quantity of concrete masonry to be paid for under the various items covering such work shall be that deposited in place in accordance with the requirements of the drawings and of the Engineer The prices stated in Item ... include the cost of all centers and forms, and placing and removing them; of furnishing all materials; of mixing, placing and finishing the concrete, and all expenses incidental thereto.

ART. 17.—VITRIFIED PIPE AND SPECIALS

1. All pipe and specials shall be first quality, salt-glazed vitrified clay or stoneware, of the dimensions stated in the accompanying Table of Minimum Dimensions in Inches of Vitrified Pipe.

TABLE OF MINIMUM DIMENSIONS IN INCHES OF VITRIFIED PIPE

Size	Standard		Double strength		Deep and wide socket		
	Thickness	Depth of bell	Thickness	Depth of bell	Thickness	Depth of bell	Annular space
4	9/16	......	......	......	⅝	1 11/16	½
6	¾	1⅞	......	......	¾	2⅛	[illegible]
8	13/16	2	......	......	¾	2¾	[illegible]
10	⅞	2⅛	......	......	⅞	2	[illegible]
12	1	2¼	......	......	1	3	[illegible]
15	1⅛	2½	1¼	2½	1⅛	3	[illegible]
18	1¼	2¾	1½	2¾	1¼	3¼	[illegible]
20	1⅜	3	1¾	3	1⅜	3½	[illegible]
22	1½	3	1⅞	3	1⅝	3¾	[illegible]
24	1⅝	3¼	2	3¼	1⅝	4	[illegible]
27	2	4	2¼	4		......	......
30	2⅛	4	2½	4	...	......	......
33	2¼	5	2⅝	5		......	......
36	2½	5	2¾	5		..	......

2. The Engineer shall designate where standard, double-strength or deep-and-wide-socket pipe shall be used In general, standard pipe shall be used for underdrains, double-strength for the larger sizes of sewers; and deep-and-wide-socket pipe for sewers which carry only sanitary or house sewage

3 The pipe shall be manufactured at a temperature producing a tough vitreous material without cracks, warps, fire cracks, blisters or other imperfections which, in the judgment of the Engineer, render them unsuited for use. They shall be fully and smoothly salt-glazed over the entire inner and outer surfaces, except that the inside of the bell and the outside of the spigot may be unglazed for two-thirds the depth of the bell On all other portions of the pipe the glazing shall completely cover and form an integral part of the pipe body. If left glazed, the inside of the bell and the outside of the spigot shall be scored in three parallel lines extending completely around the circumference. When broken, vitrified pipe shall show dense and solid material, without detrimental laminations; it shall be of such quality that it can be cut with a chisel and hammer, and shall have a metallic ring when struck with a hammer.

4. Any diameter of the pipe shall not vary more than 3 per cent above or below the standard diameter, and the excess of the longest diameter over the shortest in the same pipe shall not be more than 3 per cent. No pipe shall deviate more than 1/4 in. from a straight line in its length, and the ends of the barrel shall be at right angles to its axis.

5. All pipe will be inspected upon delivery, and such as do not conform to the requirements of this contract will be rejected and shall be immediately removed by the Contractor, who shall furnish all labor necessary to assist the Inspector in inspecting the material.

6. The entire product of any factory may be rejected when, in the judgment of the Engineer, the methods of manufacture fail to guarantee uniform results, or where the materials used are such as to produce inferior pipe, as indicated by repeated failure to comply with requirements similar to those of this contract

7. The prices agreed upon under Item . . . , shall include the entire cost of furnishing and delivering all vitrified pipe, branches, bends, stoppers and other fittings. Payments will be made for all accepted branches and fittings set in the pipe line or its appurtenances in accordance with the price list of Item . . . and the discount therein stated The quantity of pipe for which payments will be made will be based on measurements of the length of the invert lines of the sewers, the length of the manhole inverts and the lengths of branches and other fittings being deducted from said measurements. [There is a great variety in the methods of paying for pipe sewers, and it is not unlikely that methods best suited for large work may not be most desirable for small work in short, independent sections.]

ART. 18.—CEMENT CONCRETE SEWER PIPE

[These requirements are substantially those recommended in 1913 to the American Society of Municipal Improvements by a committee consisting of E. J. Fort, Rudolph Hering and A. J. Provost, Jr.]

1. Cement concrete sewer pipe, without reinforcement, shall be of the hub and spigot type, conforming in dimensions to the standard drawings. Variations not greater than 1/2 per cent. from such dimensions will be permitted The minimum lengths, thicknesses, depths of hub and annular spaces for the several sizes of cement concrete pipe, shall be as stated in the accompanying Table of Leading Dimensions of Cement Concrete Pipe. Egg-shaped sections for 12-in and larger sizes shall have flat bases and shall be equal in quality to samples to be seen at the office of the Engineer

Table of Leading Dimensions of Cement Concrete Pipe

Diameter, inches	Length, feet	Thickness, inches	Depth of socket, inches	Minimum annular space, inches
6	2	¾	2½	⅝
8	3	⅞	2½	⅝
10	3	1	2⅝	⅝
12	3	1¼	2¾	⅝
15	3	1½	2¾	⅝
18	3	1¾	3	¾
20	3	2	3	¾
22	3	2¼	3¼	¾
24	3	2½	3½	1

2. The concrete used in the manufacture of cement concrete pipe shall be composed of a mixture of Portland cement, sand, and broken stone or gravel, suitably graded and equal in quality to similar material specified in Articles 8 and 9 When concrete pipe is broken it shall appear homogeneous, be entirely free from cracks or voids and generally uniform, showing pieces of fractured stone or gravel firmly imbedded in the mortar

3. The materials used in its manufacture, the process of manufacture, and the marking and dating of pipe shall be subject to inspection at the factory by inspectors designated by the Engineer All pipe shall have the Manufacturer's name and the date of molding clearly impressed on the outer surface, as an identification mark. Methods of molding, trimming and seasoning cement concrete pipe are left to the discretion of the Manufacturer. As furnished it shall be without warps, cracks or imperfections, and shall present smooth inner and outer surfaces with no stones visible.

4. After having been thoroughly dried and then immersed in water for 24 hours, sample pieces of cement concrete pipe of about 10 sq. in. superficial area, with broken edges, shall not absorb more than 7-1/2 per cent of their weight of water

5. No pipe shall be delivered on the work or used within . . . days after manufacture.

6. The manner of forming and joining spurs and branches with hubs of standard dimensions to cement concrete pipe shall be such as to insure a tight union of ample strength to meet the requirements of the work.

ART. 19.—LAYING VITRIFIED AND CEMENT CONCRETE PIPE

1. The pipe lines shall be constructed of pipes of such sizes and laid to such lines and grades as are shown on the drawings, or as directed by the Engineer. Unless otherwise directed, the joints shall be made as required in Clause 6 of this article.

2. When the sewer is to be laid without a cradle, the earth forming the bed shall be carefully freed of stones. The pipe shall then be evenly bedded in the earth over the lower third of its circumference, great care being taken to remove only enough of the earth to leave a uniform support for the entire length of the pipe, except the bell, under which a recess shall

be excavated to a sufficient depth to relieve it of any load and to allow ample space for making the joint. In case the bed trimmed in the bottom of the trench is too low, earth shall be thrown into the bottom and thoroughly rammed, and a new bed trimmed for the pipe. It is forbidden to raise the grade of the pipe by ramming earth beneath it. When the pipe has been bedded satisfactorily and the joint made, the recess under the bell shall be refilled with earth and enough earth shall be refilled and tamped on each side of the pipe to hold it securely in place, care being taken not to disturb the position of the pipe during this process.

3. The concrete cradle shall have a thickness of at least 6 in., unless otherwise directed; in rock excavation the amount of concrete shall be sufficient to fill the space about the pipe. The concrete for the full width of the cradle shall be deposited continuously to the height of the outside bottom of the pipe. Before this concrete has set the pipe shall be evenly bedded therein, so as to have a uniform support for its entire length, and the remainder of the concrete shall be immediately deposited and carefully tamped in such a manner as to avoid changing the position of the pipe.

4. Where the sewer is to be laid in a gravel or broken-stone cradle, the latter shall consist of gravel or broken stone passing a 1-in. mesh and retained on a 1/8-in. screen. This shall be deposited and tamped for the full width of the trench to the height of the outside bottom of the pipe. The pipe shall then be bedded on this material and the remainder of the gravel deposited and carefully tamped so as to avoid disturbing the pipe but giving a uniform support to its entire length.

5. All pipe, previous to being lowered into the trench, shall be fitted together dry on the surface and matched, so that when jointed in the trench they shall form a true line of tubes. Each pipe shall be laid so as to form a close joint with the next adjoining pipe, and bring the inverts continuously to the required line and grade

6. Cement joints shall be made as nearly water-tight as possible and in the following manner: A closely twisted gasket of hemp or jute, of suitable diameter to bring the pipe into their proper relative position but in no case less than 3/4 in., and long enough to pass around the pipe, shall be soaked in neat Portland cement grout and then rammed into the annular space between the bell and hub with suitable calking tools. The remainder of the joint shall then be filled with cement mortar applied with the hands protected by rubber mittens; this mortar shall be used as soon as mixed and shall be composed of equal parts of Portland cement and sand, mixed dry with enough water added subsequently to give to it the proper consistency. This mortar shall be well pressed and calked into place, after which the joint shall be beveled off with mortar for a distance of 2 in. from the outer edge of the bell. The joint shall be wrapped in unbleached cotton cloth, securely tied to prevent the mortar from slipping or being otherwise injured. No surplus mortar or other foreign substance shall project into the pipe from the joints, and, if necessary, they shall be cleaned with a go-devil or disk swab attached to a rope or rod sufficiently long to pass two joints from the end of the pipe last laid and pulled forward as the work progresses, or in some other manner satisfactory to the Engineer. The joints on the inside of all pipe sewers larger than 15 in. in diameter shall be carefully filled with mortar and wiped smooth and flush with the surface of the pipe.

7. Where plastic joints are specified, they shall be thoroughly calked with a closely twisted gasket of dry hemp or jute, long enough to go around the pipe and of sufficient thickness to hold the pipe securely in their proper relative positions. The plastic compound to be used in jointing the pipes shall be that known as the.................. manufactured by the.......................... of.... ...., or other plastic jointing material satisfactory to the Engineer. The compound shall be heated in a gasoline or other suitable furnace to a temperature slightly above that at which it can be poured rapidly and smoothly, and it shall be kept at this temperature until used. After the pipe joint has been calked, the melted compound shall be poured into the joints with the aid of a joint runner or gasket, in the same way that lead joints are poured. In case the pipe joint is not completely filled, the unfilled part of the joint shall be poured again with hot material so as to form a complete water-tight joint. Wherever permitted sections composed of two or three pipe, may be jointed at the side of the trench provided the pipe are held firmly in correct alignment. In lowering the sections so made into the trench, a piece of timber shall be run through the pipe to support their weight and prevent the joints or bells from being broken.

8. Plain mortar joints shall be made as follows: Before a pipe is laid, the lower half of the bell of the preceding pipe shall be plastered on the inside with stiff mortar of equal parts of Portland cement and sand, of sufficient thickness to bring the inner bottoms of the abutting

pipe flush and even. After the pipe is laid, the remainder of the bell shall be thoroughly filled with similar mortar, and the joint wiped inside and finished to a smooth bevel outside.

9. The mouth of the pipe shall be carefully protected from all blasts, and rock excavation shall be fully completed at least 30 ft. in advance of the laying of the pipe. In all cases the mouth of the pipe shall be protected by a board or other stopper fitted to the pipe so as to prevent earth and other substances from entering.

10. In no case shall water be allowed to rise in or about the pipe before the mortar of the joint has become thoroughly set No walking on or working over the pipe after they are laid, except as may be necessary in tamping the earth and refilling, will be permitted until they are covered with earth to a depth of 12 in

11. Branch pipe shall be provided and laid as and where directed. Open ends of pipe and branches shall be sealed with stoneware stoppers, cemented into place in an acceptable manner The branches shall be laid so that the tap is on an angle of 30 degrees above the horizontal

12. The prices agreed upon under Item... shall include the entire cost of laying the pipe, branches and fittings, sealing their ends and supplying the stoppers for the seals, and supplying the materials and all labor for making the joints. Payments will be based on measurements of the length of the invert lines of the sewers, the length of the manhole inverts being deducted from said measurements Concrete cradles shall be paid for at the stated price per cubic yard in Item. . and gravel or broken stone cradles at the stated price per cubic yard in Item....

ART. 20.—LAYING CAST-IRON PIPE

1 The materials shall be distributed by the Contractor as required, and care shall be exercised to prevent any injury in handling Proper tools and implements satisfactory to the Engineer for safely handling the pipe and other materials shall be provided by the Contractor, and particular care shall be exercised to prevent the abrasion of the pipe coating. Wherever the coating shall be found to have been rubbed off to an unusual extent, the part shall be thoroughly cleaned and recoated by the Contractor, with Smith's Durable Metal Coating or other paint satisfactory to the Engineer, and the Contractor shall keep on hand a suitable supply for such purpose

2. All specials and other appurtenances required for the pipe line shall be set by the Contractor as directed by the Engineer without additional compensation.

3. Every pipe shall be cleared of all débris, stone, dirt, etc , and inspected for cracks before being laid, and if found cracked the cracked portion shall be cut off by the Contractor before laying The bell of the pipe shall be wiped out before inserting into it the clean spigot of the next pipe, which latter shall then be shoved home firmly against the bottom of the bell in such a manner as to prevent the pipe becoming displaced after the joints are poured with lead. The pipe shall be laid to line and grade as required.

4. Only good sound hemp yarn or jute packing, braided or twisted, cut off in lengths as necessary and tightly driven home, shall be used Said yarn shall be furnished by the Contractor.

5. The depth of the lead joints shall be about 2 in., measured from the face of bell after calking to the back side of the groove. The lead shall be furnished by the Contractor, and shall be of the best quality, pure and soft and suitable for calking. The lead melting pot shall be at all times kept within easy reach of the joint, at a distance of not over 50 ft , so that the lead shall, under no circumstances, be chilled in being carried from the melting pot to the pipe The joint shall invariably be run at one pouring, using such ladles as may be necessary, and shall thereafter be calked by skilled mechanics, using at least two sets besides the small set or chisel, in such a manner as to give a permanently tight joint flush with the end of the bell, without straining either the pipe or bell.

6. The length of pipe to be paid for will be based upon the measurements taken along the center line of the pipe, including specials and other appliances measured along their center lines.

7. The price per linear foot agreed upon under Item... shall include the cost of furnishing the yarn, lead and all other materials used for laying and jointing the pipe, together with all cutting of the pipe and other labor necessary for the same.

ART. 21.—INLET AND CATCH-BASINS

1. Inlets and catch-basins shall be built wherever shown on the drawings and at such other places as may be ordered by the Engineer during the progress of the work.

2. Inlets and catch-basins shall conform in every respect to the drawings; they shall be made perfectly water-tight by plastering the walls with cement mortar 1/2 in. in thickness and grouting any joints where the Engineer considers this necessary. They shall be furnished with cast-iron covers when required by the drawings and connected with the sewers by vitrified pipe and such bends and slants as may be required. All stones shall be cut smoothly and accurately to the dimensions and shapes shown on the drawings. Where the trap is formed by stones, they shall have perfect joints made water tight with cement mortar.

3. If flagstones are used in inlets and catch-basins they shall be sound, of uniform thickness throughout, and free from imperfections. They shall be dressed smooth on the edges so as to make close-fitting joints, have square corners, and be of the dimensions shown on the drawings.

4. When inlets and catch-basins are to be rebuilt, the contract price stated in Item . . . shall include taking out the old inlets, rebuilding them anew at the same or such other location as may be ordered, but at no greater distance away than the nearest street. The Contractor must supply all the labor and materials required to build them anew, in accordance with the drawings for new structures. All castings set or reset in connection with the rebuilding of inlets and catch-basins shall be in accordance with the standard drawings. The old castings shall become the property of the Contractor. The Contractor shall furnish and set the curb in the gap formed by the removal of an old inlet that has been reconstructed at another location, without additional charge When it is necessary to lay a new pipe connection in the rebuilding of an inlet or catch-basin, payment will be made for the pipe used at the price stated in Item . . . When an old inlet or catch-basin, unsuitable for rebuilding, becomes unnecessary by reason of the construction of a new structure, the Contractor shall remove the old structure without additional compensation and the old material shall become his property

5. In building or rebuilding inlets and catch-basins, unless otherwise ordered, the Contractor shall supply any materials and labor necessary to pave or repave the roadway and sidewalk in a manner which will restore them to their condition before the work began, in the judgment of the Engineer All sidewalk paving or repaving and all roadway paving or repaving on a gravel base shall be done without extra compensation. All roadway paving or repaving on a concrete base will be paid for at the price fixed in Item. . . . The price paid for each new inlet and catch-basin shall include a length of not more than 25 lin. ft. of vitrified pipe in place, complete, for connection with the sewer; any excess will be paid for at the price of vitrified pipe stated under Item . . ., the price of excavation stated under Item. . . , and the price of pipe laying stated under Item. . . Where existing inlets or catch-basins are to be reconnected to a new sewer, the connection shall be made entirely new from the inlet or basin to the sewer, in accordance with the drawings Any necessary repairs or alterations to the inlet or basin shall be made by the Contractor without additional cost.

6. When telephone or telegraph posts, gas lamp posts or electric light posts must be moved, the Contractor shall employ the company or municipal department owning them to move them, and he will be reimbursed for this expenditure, the amount to be shown by presenting the receipted bills for the work.

7. The price agreed upon under Item . . shall include in addition to the charges for the work and material enumerated in Clause 5, the cost of furnishing materials for and placing the concrete and brick masonry, the cost of furnishing and placing all dimension stones, the cost of setting the cast-iron frame and cover, and the cost of excavation, backfilling and grading about the structures.

ART. 22.—MANHOLES AND WELLHOLES

1. Manholes of every type shall be built into the sewers of the size, form, thickness and in the positions shown in the drawings, and they shall be carried up to within . . . in. of the established grade or to some other elevation, as directed When not built up to within . . . in. of the established grade of the street, the masonry or concrete shall be covered, when so directed, with bluestones not less than 5 in. thick or with an approved reinforced concrete slab to support the head.

2. On all oval or circular sewers of less than 3 ft. horizontal diameter, constructed in any other than hard rock excavation, the manholes shall have a foundation as shown in the drawings. In hard rock, the manholes may be founded at the springing line of the sewer, but the rock shall be shaped out to receive the masonry.

3. Brick manholes shall be built from templets placed at top and bottom to guide the work, with not less than eight lines drawn between them, unless the Engineer authorizes the omission of their use. The connection with the arch must be true and secure, and in the manner shown on the drawings The joints are to be neatly struck and pointed on the inside, and the outside of the brickwork must be neatly plastered with cement mortar as the work progresses. An approved proportion of brickbats may be used in manholes.

4. Concrete manholes shall be built of the sizes and dimensions shown on the drawings. The concrete shall conform to the requirements of Article 16. If permitted by the Engineer, the shaft of the manholes may be constructed of reinforced concrete pipe, in which case great care must be taken to secure tight joints.

5. Iron steps of the dimensions shown in the drawings are to be built into the brickwork or concrete 15 in. apart vertically, unless otherwise indicated in the drawings. They shall be galvanized, or coated with red lead paint or coal tar varnish.

6. Unless otherwise indicated on the drawings, every manhole shall be provided with a cast-iron frame and cover of the dimensions shown in the drawings The covers shall be free from imperfections, thoroughly cleaned and coated with coal tar varnish of approved quality, and if so ordered be provided with a galvanized bucket of the dimensions shown in the drawings The weights of the castings shall be certified by the foundry furnishing them to be as follows: Ventilating cover and frame, complete,. . . lb ; closed cover and frame, complete,. . . lb. The castings shall conform as to quality to the requirements of Article 13. The cover shall have a continuous and even bearing on the frame, and be properly set to avoid rocking. All inequalities, projections or roughness on abutting surfaces of the cover and the frame shall be removed, and the cover fitted into the frame as neatly as possible without jamming

7. Wellholes shall have brick walls 13 in thick, unless otherwise shown on the drawings, with such openings, slants and bullseyes as may be required. The foundation shall be built of stone masonry or concrete, upon a hard approved bottom or upon the sewer cradling extended as may be directed. Upon it flagstones or granite block pavement not less than 4 in. thick shall be laid to the proper grade and well bedded in cement mortar, forming a rectangular surface, the smaller side of which shall not be less than the exterior diameter of the wellhole. The brickwork shall be built on this foundation from templets to guide the work. The inside joints shall be carefully pointed and the outside of the brickwork shall be plastered with cement mortar as the work progresses. The connection with the sewer shall be true and secure, and at an angle of 45 deg in the direction of flow in the sewer in case the wellhole does not rise from the side walls of the sewer.

8. Drip stones of flagstone or very hard concrete shall be built into the brickwork every 5 ft., reckoned from the top of the foundation, but no drip stone shall be located at a distance less than 5 ft. from the bottom of the sewer connecting with the wellhole. They shall project half-way across the wellhole and alternate in their position, so as to break the fall of the sewage, and shall be not less than 4 in. thick and in length equal to the interior diameter plus 9 in. and in minimum width 4 in. greater than half the inside diameter of the wellhole.

9. The top of the wellhole shall be drawn in all around to within 3 ft. of the confirmed grade and to a diameter of not less than 2 ft., and then covered with a flagstone or concrete slab 6 in. thick, or the brickwork may be extended to the confirmed grade and provided with a manhole frame and cover, as may be directed.

10. The price per cubic yard agreed upon in Item. . . is for the entire cost of construction of the manholes, of furnishing all materials except the steps, and of placing all materials, including all metal work.

ART. 23.—CURBING, GUTTERS AND SIDEWALKS

1. In general, all curbing and sidewalk paving disturbed in the execution of this contract shall be relaid in accordance with the requirements of the municipal department in charge of street work. The Engineer shall determine whether the Contractor shall restore the curbing and sidewalk paving to its condition immediately before the beginning of work

under this contract or shall carry out the work in accordance with the latest local specifications for new curbing and sidewalks of the same general class. [In case work of the latter nature is desired, it should be definitely specified and unit prices for it required from the bidders.]

2. Gutters of dirt, macadam, telford or gravel roadways shall be paved where directed with cobbles, field or random stones of satisfactory quality, none of which shall be less than 5 in. in any dimension and all of which shall be at least 8 in. in two dimensions. The stones shall be carefully laid by hand to line and grade, well bedded in fine gravel or sand and thoroughly rammed. The joints shall be filled with sand. Payment for all materials and labor required for gutter paving will be made under Item... Should such pavement, with its joints filled with Portland cement grout or sand, settle or become displaced, or should there be any defective work of any kind, such work must be removed at once and replaced by the Contractor in a satisfactory manner without additional compensation.

3. Curved stone curbing shall be in lengths of at least 5 ft. and straight curbing 6 ft. It shall be of first quality .... at least 8 in. wide on top and 10 in on the base and 24 in. deep. No closure shall be less than 4 ft. in length, and there shall be no offset in the finished curb, unless called for by the drawings or by the Engineer. Where stone curb is set adjacent to a grate-top inlet or where a grate-top inlet is built or rebuilt adjacent to curb already set, the curb shall be dressed the entire depth, so as to allow the casting to fit closely to it.

4. Curbstones shall be cut to bevel with the side walls of catch-basins and inlets, if so required by the drawings, and be dressed on the ends, if necessary, to fit the cast-iron covers, which shall conform to the general level of the sidewalk and be set a sufficient distance from the edge of the curb to prevent displacement or injury by passing vehicles. Where curbs upon which the casting is to rest are out of line or grade, or too short for the purpose, they shall be reset and adjusted as directed, without extra charge

5. Concrete curbing shall be composed of a mixture of one part of Portland cement and six parts of sand and ballast, in the absence of other directions, and, unless required by the drawings to be of a different cross-section, shall be 6 in. wide on top, 18 in. deep, with a vertical face and a back sloped 1 to 5 The lumber for forms shall be dressed on the edges and on the side next the concrete, and be set securely so that the curbing, when completed, shall conform accurately to line and grade After the concrete has been deposited, it shall be spaded back from the face of the form to a depth of at least 8 in., and to a width of not less than 3/4 in. at the top. The space thus formed shall be filled with a mixture of 1 part of Portland cement and 1-1/2 parts of sand, by volume, and the concrete and mortar shall then be thoroughly spaded and tamped. A top layer of the same mortar 3/4 in. thick shall be applied immediately and thoroughly troweled to a smooth, uniform finish, special care being taken to produce a perfect bond between the mortar and concrete After the forms have been removed, all faults of any sort shall be filled with mortar and smoothed, so that the top and the face for a depth of 8 in. shall be free from defects. The fresh concrete shall be sprinkled and protected from the weather as directed by the Engineer.

6. Where an open or covered cross gutter or pipe drainage channel exists in the surface of the roadway, which will be rendered useless by the construction of a storm inlet, the Contractor will be required to remove the whole of it and lay or relay the pavement to the grade and surface designated by the Engineer. This work shall be done without extra charge, and all iron pipe and gutter covers removed shall remain the property of the city.

7. Where granolithic sidewalk is required, the site shall be excavated and graded to the width directed, to a subgrade 18 in. below and parallel to the top of the finished pavement where the excavation is in earth. The bed shall be thoroughly compacted by ramming to the prescribed lines. If the excavation be in solid rock that requires blasting, the subgrade shall be not less than 8 in. below the finished top. On the subgrade so prepared, a foundation of clean cinders shall be placed in two layers, which shall each be well consolidated by ramming with a rammer weighing at least 75 lb. The cinders shall be well watered during ramming, and the top surface shall be brought to a height 4 in. below and parallel to the finished surface, which shall have a transverse grade 1/4 in. per foot upward from the curb. On this cinder foundation shall be placed 3 in. of cement concrete thoroughly compacted, which shall be cut by joints into blocks not larger than 5 ft. square, the joints to extend clear through the concrete. On this base, before the concrete has attained its initial set, shall be placed the wearing course, consisting of a stiff mortar of 1 part cement and sand and 1-1/2 parts of crushed granite or other stone approved by the Engineer, the largest particles of which shall pass through a 1/2-in ring and the smallest be retained on a 1/4-in. screen, free from dust, loam or earthy and organic substances. This mortar shall be laid to a full depth of 1 in.,

carefully floated, and troweled to a smooth, even surface. A drier made of equal parts of sand and cement, well mixed, shall be sprinkled in a dry state over the surface, and then floated and troweled. Joints shall be made clear through the wearing surface, directly over the joints in the concrete base, troweled with a small jointer, and the entire surface indented in a manner satisfactory to the Engineer. When the pavement is completed it shall be kept covered for 3 days, and shall be kept moist by sprinkling and thoroughly protected against freezing.

CHAPTER XVIII

OPERATION AND MAINTENANCE OF SEWERAGE SYSTEMS

The investment in sewerage systems in this country amounts, roughly, to from $10 to $40 per capita of population residing in the sewered cities. According to the special report on "Statistics of Cities, 1908," issued by the U. S. Bureau of the Census, the replacement value of such systems in cities of 30,000 inhabitants, or over, aggregates over $550,000,000, not including the systems of several large and a number of smaller cities.

In view of this investment, it is remarkable that so little attention has been given to the operation and maintenance of sewerage systems. The public, and particularly City Councils and Mayors, realize that money must be furnished for the operation and maintenance of pumping stations, but they are slow to understand the necessity of expenditures for the operation and maintenance of the sewers. In fact, few citizens or councilmen have the slightest conception of the network of sewers beneath the streets, or of the difficulties encountered by the Sewer Maintenance Departments. When a sewer fails to perform its work, however, there is likely to be serious complaint and the criticism of those in charge is often unfriendly, to say the least. One of the important duties of those responsible for the operation of these systems is to enlighten the proper authorities upon the necessity of properly caring for them, keeping them clean, repaired and ready at all times to serve their purpose. With sewers, as with most other structures, it is less expensive to make minor repairs from time to time when necessary than to allow the defects to await a more convenient time for repair. Serious damage may often be avoided if inspections are frequent and small repairs are made promptly.

Inspection.—A knowledge of the physical condition of sewers is necessary for their proper operation. As sewers are below the surface of the ground and never seen except at times of cleaning, repair, or special inspection, it is evident that such knowledge must generally be obtained through inspection.

Special structures, such as regulators, tide-gates and inverted siphons, should be inspected at frequent and regular intervals. For example, regulators ought to be examined nearly every day and siphons about once each month, while flush tanks require inspection at least once each week. Sewers in which considerable quantities of detritus accumulate should be examined three or four times a year and a general inspection should be made of the entire system once annually. The small sewers at the upper ends of systems and all sewers having exceptionally flat grades should be examined whenever flushed by hand, the interval between such inspections varying with local conditions but usually not exceeding one or two months, where systematic and thorough flushing is practised.

The general annual inspection is a continuation of the monthly inspections of the small sewers requiring flushing. Most of this work should be done during the warmer portion of the year, when the manhole covers are accessible and easily removed. The masonry sewers large enough to permit of direct internal inspection may be examined during the winter, when the temperature and quality of air in the sewers are more favorable than during hot weather.

The annual inspection should be sufficiently thorough to reveal any defects in the masonry of manholes or large sewers and to detect the presence of unusual deposits. This may generally be done by merely noticing the stream of flowing sewage at the manholes. If there is obstruction, it will be evident at the manhole next above, where the sewage will be found to be backing up. Occasionally, a more thorough examination should be made to learn of the condition of the smaller pipe sewers. This can be done by looking through the sewers from manhole to manhole, often without artificial light or reflectors. Where necessary, mirrors may be used for throwing a pencil of light through the pipe or candles on floats may be sent through the sewer if gases are absent. By means of such light, it will be possible to detect any serious defects in the pipe, although small cracks are difficult if not impossible to see at a distance from the manhole. Such thorough inspection need not be made annually, but should be made often enough to give the superintendent a clear knowledge as to the general condition of the sewer system.

Careful and complete records, conveniently indexed, should be made of all inspections. Where repairs are found to be necessary, even though they be slight, like the pointing of the brickwork above the frost line in manholes, they should be promptly made.

When a sewer is to be entered or a lighted lamp or candle is to be lowered into it, great care should be exercised to avoid danger of explosion. Men accustomed to this work will quickly perceive the presence of illuminating gas or gasoline vapor by the odor. This is the safest method of testing the air, but the observer should be careful to note whether the air is entering or emerging from the manholes, otherwise he is likely to mistake the absence of odor for the absence of gas in the sewer. If it is necessary to enter the manhole to determine the presence of gas, this should be done without a light, unless it be an electric lamp, and the man entering should wear a life belt with a line leading to his helpers at the top of the manhole. Although seldom done, it is always wise to open several manholes on the sewer to be entered some little time before the entrance is to be made, in order to provide a change of air within the sewer.

An inspection in, or even very close to a manhole, should never be attempted by one man alone; the inspector should have at least one helper both for his protection and that of the public, and usually more than one. The helper should remain standing at the top of the manhole to warn approaching persons of the opening. Where the inspector is to go from manhole to manhole through the sewer a second helper should precede him to the manhole below that at which he enters. When the inspector has reached the second manhole, the second helper signals the one at the first manhole, who replaces the lid and passes on to the third manhole, awaiting the arrival of the inspector at this point. Three men constitute the minimum safe size of gang for such inspection and preferably two men should go together through the sewer.

Deposits in Sewers.—Deposits which are found in sewers may be subdivided into two classes, first, heavy deposits consisting of sand, gravel or road detritus, which require scraping or some similar process for their removal, and, second, deposits of light organic substances which may be flushed along the sewer until they reach a point beyond which there is sufficient velocity and depth of flow to carry them along. If the heavy deposits are allowed to accumulate, the capacity of the sewer will be materially reduced and dams are likely to be formed behind which the sewage will be impounded and the organic matter will settle and decompose, giving off offensive odors. In the smaller and flat sewers, especially at the upper end of a system, organic matter is likely to accumulate, due to lack of sufficient depth of flow and velocity to carry it along.

Much has been said about different means of flushing, and while attention should be given to this subject, the authors are inclined to the view that there has been a tendency in some cases to overestimate the ill effects of comparatively slight accumulations. It is certain that little flushing is done in the larger cities, with comparatively few resulting stoppages and without complaint of objectionable odors.

The deposits found in the larger combined sewers and storm drains consist of sand and road detritus, the character and amount of which depend to some extent upon the natural soil and the street surfaces, as well as upon the slope of the surface of the land in general. Where organic deposits are covered with water decomposition is accompanied by disintegration and the coarse material which was deposited passes away as finely divided suspended matter, or is carried to the surface in masses by entrained gases and borne along by the flowing sewage.

Heavy oils and tars mixed with detritus form a sort of cemented deposit which will not be scoured or flushed out of the sewer by ordinary velocities of flow. Such deposits are often found below connections from gas works, unless special precautions are taken to prevent the discharge of tar. Even where provision is made for recovering tar from the gas wastes, quantities of it and of heavy oil are likely to pass away from the plant and find their way into the sewer, unless some sort of filter beds are provided which will remove such substances from the water.

Grease from hotels and restaurants is a cause of frequent partial or complete clogging of sewers. The large quantities of hot water containing the grease are not sufficiently cooled for the grease to be intercepted by the traps and it accordingly is deposited on the walls of the house connections and sewers. E. S. Dorr, head of the Boston sewerage work for many years, reports that this trouble became so important in the localities near large restaurants that he made continuous efforts to have satisfactory grease traps installed to prevent grease from getting into the sewers. The largest traps made by manufacturers of plumbers' supplies were entirely too small for this purpose. The quantity of hot water being received all the time kept them constantly heated and allowed the grease to be carried through to the sewers. One large restaurant made an effort to solve the difficulty by a basin 4 × 10 ft. in plan by 4 ft. deep, which was crossed by several baffles. This improved conditions so that where formerly they removed about 175 lb. of grease per week, they now succeed in getting on the average about 900 lb. As much of this may be sold for 5 cents a pound, the trap will eventually pay for itself, although in this particular case the original cost was about $800.

An interesting instance of accumulations in a sewer in Lynn, Mass., was described before the Sanitary Section of the Boston Society of Civil Engineers, by A. C. Townsend (*Jour. Assoc. Eng. Socs.*, 1904, p. 239). In this case a large tank of boiling soap was accidentally discharged into a 36-in. brick sewer having a slight grade. The weather at the time was cold and for 300 or 400 ft. the soap congealed and nearly filled the sewer. It was necessary to send men in and actually cut out the soap.

Most of the Manhattan sewers, the mouths of which are tide-locked and the bottoms of which lie below high tide, were found by the Metropolitan Sewerage Commission to contain considerable deposits of silt and sewage solids forming as a rule a dense mass difficult to remove without the use of tools. In neighborhoods where considerable grease escapes with the sewage the rise and fall of the tides has coated the sides and tops of the sewers with congealed grease, in some cases as much as a foot in thickness. In the sewers where steam and hot water entered the odors from the cooked sewage are unusually disagreeable.

A description of conditions found inside a large sewer in Columbus, Ohio, was given by Julian Griggs, formerly chief engineer of the Department of Public Service of that city, in *Engineering News*, vol. xliv, p. 443. The deposit is described as being mostly road detritus mixed and stratified with layers of tar from 1/8 to 1/4 in. thick, and from 1 to 2 in. apart. The following description of growths in the sewers is of particular interest:

> "Toad stools up to 3-1/2 in. in diameter in all stages of growth and decay were found on the sides and top of the sewer in abundance, and under the part having a cover of 40 ft. . . . The mycelium of a fungus common in coal mines, which resembles the tough fibrous roots of a tree, was found 9 in. in length, growing in patches from the top of the sewer; and in one place a thick bunch or cluster 20 in. in diameter and 30 in. in length, was attached to the side of the sewer above the spring line."

A description of stoppages in a sewer system was given in *Jour. Assoc. Eng. Socs.*, vol. xxxiii, 1904, p. 227, by F. Herbert Snow, Chief Eng. of the State Department of Health of Pennsylvania, as follows:

> "During the year, in the street mains and connections, there were 482 ordinary stoppages and 134 more on private property, making a grand total of 616 stoppages chargeable to the operating account of the sewer system. In analyzing the causes of these stoppages* it was found that
>
> Grease caused 19 in mains and 8 in outside connections
> Sand caused 25 in mains and 26 in outside connections
> Rags caused 83 in mains and 47 in outside connections
> Breaks caused 16 in mains and 21 in outside connections
> Misc. caused 79 in mains and 128 in outside connections
>
> "The 222 stoppages in the mains cost $1063, or $4.79 per stoppage. The 260 stoppages in the outside connections cost $594, or $2.28 per stoppage. The total cost of each one of the above causes according to the classification in the table was as follows: grease $189, sand $208, rags $444, breaks $139, miscellaneous $677. But most of the miscellaneous stoppages were caused by the accumulation of grease between the street line and the sewer main, and about one-half of the inside stoppages originated from this source."

A description of conditions in Newton, Mass., is given in the same place by Dana Libby, deputy street commissioner in charge of sewers of that city:

> "The streets of Newton are lined with shade trees, and their roots readily follow down through the less compact earth in the sewer trench and find defective joints if any exist. The underdrains become clogged with these roots much more frequently than the sewers, as they are laid with open joints, but

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* This apparently refers to the 482 "ordinary stoppages;" the figure 8 for stoppages caused by grease in outside connections should probably be 38.—M & E.

the number of stoppages in sewer pipe, due to an accumulation of roots, has been far greater than was ever anticipated."

In the same discussion it was stated that in 1903 there were 15 stoppages in main sewers in Waltham, Mass. Of these 8 were in 6-in. pipes, 6 in 8-in. pipes and 1 in a 10-in. pipe. Roots from trees caused 8 stoppages, a brick one, sticks two, ribs of an umbrella one, paper one, ice one, and one by a cause undetermined. The average number of stoppages for four years was 14. At Brockton, Mass., stoppages in separate sewers were said to be practically unknown, perhaps four or five in eight years. In 1903 there was one stoppage in 1700 house connections, the standard size being 5 in. A shoe factory employing about 2500 persons was served by one 5-in. connection.

Particular attention should be given to the condition of sewers in the immediate vicinity of industrial plants such as gas works, packing houses and tanneries, from which large quantities of suspended matter likely to be deposited may be discharged. Many cities have adopted ordinances sufficiently broad to prevent the discharge of material which will prove injurious to the sewers or interfere with their successful operation. While the enforcement of such ordinances may be difficult, it furnishes a means of avoiding the trouble and expense resulting from such deposits.

Flushing Sewers.—Sanitary sewers and the small laterals of combined sewer systems are generally cleaned, if at all, by flushing. There are several methods of doing this work. Some have held that small lateral sewers should be flushed daily, on the theory that none of the organic suspended matter should be allowed to accumulate in them and remain to putrefy. To provide for daily flushing many types of flush-tanks have been designed, some of which are illustrated in Volume I. Much trouble has been caused by the clogging of the aperture through which water enters the tank so that in some places it has been found necessary to inspect the tanks almost daily to make sure that they were operating with the desired frequency. This has taken so much time that some engineers have substituted for each tank a simple water connection, from which a properly located manhole can be filled when desired by temporarily closing its outlet, which is opened as soon as the desired quantity of water has been stored. In some cases it has taken little more time to flush the sewers in this manner than to attend to the automatic flush-tanks. It has the advantage of requiring water only while flushing is actually going on and if conditions do not require daily flushings a saving in water is likely to result.

Still another method is to flush the sewer by means of a direct water connection of good size, about 1 in. when a good pressure is available. Such a connection is opened by a long-handle socket wrench, and the sewer can be thoroughly flushed in the time a manhole can be filled and discharged. This scheme has met with some favor because it oids the trouble sometimes experienced in temporarily closing a sewer hile the flushing manhole is being filled.

Many of the older and larger systems are flushed with a large stream from a fire hose attached to a hydrant. For such flushing the hose is carried upon a reel in a wagon from street to street, making a circuit of the city. At least three men are required and it is usually more economical to provide four. One objection to this method may come from the water department or company, which may object to having the sewer employees operating the hydrants. A good method of meeting this objection is to allow the water department to furnish a man to attach the hose to the hydrant and to attend to operating the gate. Where this is not done a memorandum should be made of all hydrants opened, which should immediately be turned over to the water department so that they may be inspected. By adopting the former method this inspection is made unnecessary.

Much discussion has arisen over the propriety of charging sewer departments for water used for flushing or other purposes. Whatever the final decision may be, in any case there can be no doubt that the quantity of water so used should be measured by meter and made a matter of record, otherwise there will be a tendency toward waste, and the water department will have no record of the purpose for which this quantity which has been furnished to the city has been used. Pipes supplying flush-tanks and flushing manholes should be metered in the usual way. Where flushing is done by hose a portable meter mounted on a short plank provided with handles should be used. It can be kept attached to the hose at a point near the end to be attached to the hydrant, thus avoiding the necessity of connecting and disconnecting the hose with it each time.

Where sewers are flushed by the hose method the system is usually given a thorough cleaning each spring and fall, and a less complete flushing at intervals during the summer. It is usually impracticable to do such flushing during the winter in the northern part of this country.

In a discussion of methods of sewer cleaning, published in the *Journal* of the Association of Engineering Societies, vol. xxxiii, Bertram Brewer stated that a thorough cleaning was given the sewers at Waltham, Mass., every spring and fall and that they were flushed on the average five times during the summer season, at a cost of $6.56 per mile for the entire system. At Waltham, as at Newton and Medford, Mass., pipes from the water mains discharged into summit manholes which were at a long distance from hydrants. Flap gates held back the water until the manholes became filled. There were about 38 miles of sewers in Waltham with 104 flushing manholes and 117 manholes for 2-1/2 in. hose flushing, or 221 places which were regularly flushed. C. R. Felton stated that all summit manholes in Brockton, Mass., were connected with the water mains, some with 1-in. pipe and others with 1-1/2-in. pipe, under 60 lb. pressure. At Concord, Mass., W. D. Hubbard reported $20 to $25 per mile per year was spent for cleaning a separate system of 7.53 miles. The dead ends of the system were provided with 320-gal. automatic flush-tanks discharging daily. Mr. Hubbard thought these tanks were effective for a distance of about 500 ft. Where no flush-tanks were provided, the manhole was filled by hose, the sewer being closed by pushing into it a plug made of sheet rubber, backed with canvas and packed between two circular pieces of wood of about half an inch less diameter than the pipe. Sewers requiring this method were flushed twice a year.

Dana Libby stated that there were 96 miles of sewers, 80 of which were 8-in. pipe, in Newton, Mass., in 1904. Two men with a three-wheel push-cart attended to the flushing and cleaning throughout the year, covering the entire system in from four to five weeks. The system was provided with flushing manholes equipped with 1-1/2-in. water connections. Rubber-bound wooden plugs, made of the right size to fit the outlet, were used to stop the sewers until the manholes were filled, when they were drawn out and the water allowed to flow through the sewer, giving it a satisfactory flushing.

At Melrose, Mass., according to W. D. Hunter, a separate system of about 35 miles was cared for as follows: Starting at the summit the laterals were flushed or cleaned toward the mains and then the mains were cleaned, sweeping everything down to the sump, where the local sewer connected with the metropolitan intercepter and any deposits could be readily removed. The cleaning or scraping was done by a steel hoe having the shape of the pipe with a joint or hinge so that in pushing it backward, it partly collapsed or shut up. Back of this hoe was a follower, consisting of a bag or bundle of bags made into a roll 2 or 3 ft. long and wound with a small rope so as to fill the smaller pipe entirely. The follower tended to hold back the water and when pulled into the manhole there was a rush of sewage tending to flush the solid matter along. Any heavy material which remained in the manhole was removed and carried to the dump. The same method of cleaning was followed in the larger pipe, except that the bag or follower did not entirely fill the sewer. It was kept on the bottom by being weighted or filled with sand. The cleaning was done once each year, usually in the winter. The annual cost of flushing or cleaning the system was equivalent to $17 per mile of sewer, including labor, teams and all incidental expense.

George A. Wetherbee stated that Malden, Mass., had 47 miles of separate sewers ranging from 6 in. to 3 ft. in diameter. The cleaning cost a little less than $5 per mile per year. The end manholes in small sewers were provided with 2-1/2-in. water pipe connections. When a

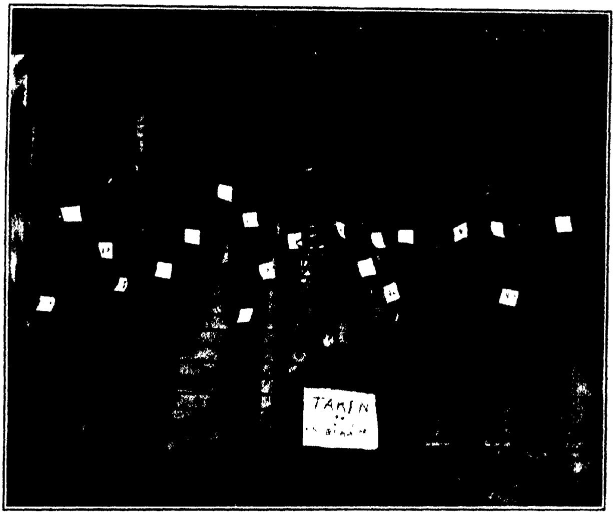


Fig. 161 —Roots removed from underdrains, Newton, Mass.

(*Facing page* 498)

wer was to be flushed, the outlet from the manhole was stopped by means of a tin form put into the sewer. The manhole was then filled with water after which the tin form was removed and the sewer flushed.

E. W. Branch reported the cost of flushing and cleaning sewers in Quincy, Mass., at $1500 annually, the system comprising 40 miles of separate sewers. The cost was, therefore, about $37.50 per mile of sewer. The sewers were flushed about once in six weeks from flushing manholes at the summits, of which there were about 125. A fungus growth appeared in some of the sewers, which was removed by means of a rattan brush. This fungus grew below the surface of the sewage and clung to the sides of the pipe, in some places leaving only a narrow channel in the center for the flow.

At Springfield, Mass., where the sewer system comprised about 25 miles of masonry and 75 miles of pipe sewers, A. A. Adams reported that the flushing was done by means of direct connections to the water system at all terminal and some intermediate manholes. The system was flushed systematically once in four to six weeks, which proved sufficiently often.

In the report of the Massachusetts State Board of Health for 1898, page 674, is a description of the trouble caused by the growth of the fungus *leptomitus* in the main sewer of Westboro, Mass. This organism grew on the inside of the sewer and was present at times in such quantities that the sewer was clogged and it was necessary to remove the growth by scraping. The organism was found only in the portion of the sewer in which leakage occurred and its growth appeared to be in some way associated with the presence of large quantities of ground water.

Removing Roots from Sewers.—Much trouble has been caused in some cities by the growth of roots within sewer pipes. In such cases, a fine, hair-like root finds its way through an imperfect joint, and after reaching the inside of the pipe this root branches and grows, sometimes forming an enormous mass of hair-like filaments, illustrated by Fig. 161, from a photograph kindly furnished by Edwin H. Rogers, city engineer, Newton, Mass. Some engineers hold that it is useless to remove such roots from time to time, as they will soon grow again, and that it is wiser to spend sufficient money to dig up and repair the sewer, thus preventing the admission of roots.

A spring root cutter was designed and used at Newton, Mass., by C. W. Ross, street commissioner. This cutter is shown in Fig. 162, and less distinctly in Fig. 161. It is made of spring steel 1/4 in. thick and about 3/4 in. wide, with the outer edge sharpened like a knife. The ends of the springs, being small, are easily pulled into a bunch of roots and the cutting action caused by pulling the spring backward and forward is sufficient to loosen a very compact mass. The cutting spring is sometimes provided with a helical inner spring instead of the chain shown in Fig. 162, to draw the cutting spring back to its proper position after it has been stretched by being pulled.

W. D. Hubbard stated that at Concord, Mass., if there was a joint in the sewers in which there was a hole as large as a knitting needle, a root would enter it and grow from 5 to 10 ft. long. For removing such roots, he used a wire brush made of thin strips of flexible steel. Upon being drawn through the sewer the brush tore off the root where it entered the pipe.

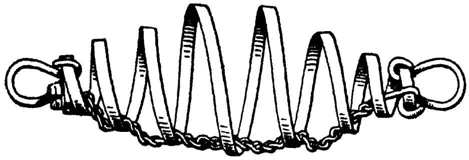


FIG. 162.—Ross root cutter.

Removal of Heavy Deposits from Sewers.—Separate sewers may be laid on very flat grades without danger of serious trouble from deposits.

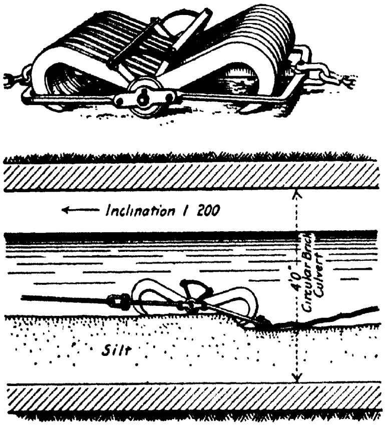


FIG. 163.—Sewer cleaning device, Walsall.

Combined sewers and storm drains, on the other hand, must have within them a velocity of at least 2-1/2 ft. per second when half full, to prevent such deposits. This fact is probably more clearly understood to-day than 50 years ago when many of the older combined sewers in this country were designed. There should, therefore, be relatively fewer future deposits in places where ample grades can be provided. There are, however, cases where sufficient grade to prevent deposit can only be obtained by pumping the sewage, and in some such cases it may be more economical to remove such deposits from time to time than to provide for continuous pumping of sewage and the occasional pumping of storm water in very large quantities. It is, therefore, important to consider methods for removing such deposits, both because those in old sewers must be removed from time to time, and because in all probability in many places it will be necessary in the future to build sewers with such flat grades that deposits will occur at certain points.

A sewer cleaner, Fig. 163, used at Walsall, England, was described by R. G. Anvel in *Engineering News*, Nov. 16, 1899. This device, weighing about 550 lb. consisted of wrought-iron claws, ten on each side, working on a common axis which permitted them to pass over irregularities in the invert. The bars above the axle prevented the claws from doubling over backward. The device was pulled backward and forward through the sewer, by means of two steam plowing engines and wire ropes.

An interesting piece of sewer cleaning was described by J. N. Ambler in *Engineering News*, June 25, 1908; this was done on a 24-in. pipe sewer 2200 ft. long at Winston, N. C. It was about half full of sand and filth, cemented by gas tar and almost entirely obstructed in places by growths of roots. A tool made of steel bands bent around hoops, Fig. 164, was used to loosen the upper part of the compacted material and to cut the roots. Water was admitted to the upper manhole, and as the cleaner was pulled backward and forward, the sediment thus loosened was flushed to the lower manhole where it settled in the water impounded behind a temporary dam. While this apparatus gave excellent results in loosening the obstructing material, the apparatus illustrated in Fig. 165, called the "butterfly," proved more effective in forcing it to the lower manhole. As the butterfly was dragged down the sewer, the wings opened, taking a considerable quantity of sediment with it. When being drawn back, the wings closed, thus reducing to a minimum the interference with the deposit. A stream of water was also used while the butterfly was being drawn down the sewer. Both the cutter and the butterfly did more effective work when weighted to hold them down in the deposit. The wire cable for drawing the apparatus was drawn back and forth by means of windlasses.

The sewer was thoroughly cleaned and put in service in two months. The foreman was paid $55 per month and laborers $1.50 per day of ten hours. Two to three laborers were employed, the total cost of labor being $144.39 and of foremen, $110. The estimated cost of cleaning devices and supplies was $20. The total cost of the work was

$254.39 equivalent to about 11.5 cents per foot. The estimated quantity of material removed from the sewer was 62 cu. yd. The cost per cubic yard is estimated at $4.10.

The cleaning of a sewer at Columbus, Ohio, is described in *Engineering News* of Dec. 27, 1900, by Julian Griggs. The sewer was large enough so that men could enter and shovel the material into buckets placed in a flat-bottomed boat 2 ft. wide by 10 ft. long, capable of holding ten buckets. The boat when full was floated to the nearest manhole and the loaded buckets raised to the street and emptied. The cost of cleaning was about $1.75 per cubic yard of material removed.

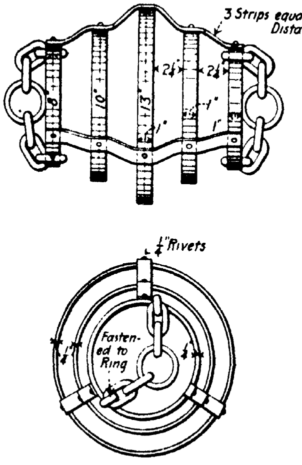


Fig. 164.—Hoop cleaner.

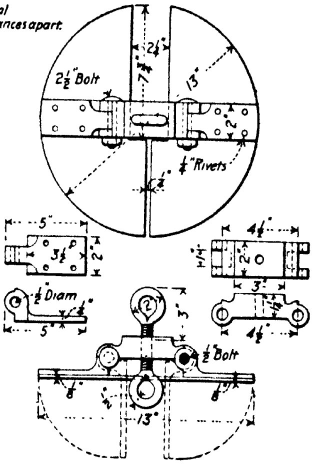


Fig. 165.—Butterfly cleaner.

The Turbine Sewer Cleaner is an apparatus consisting of a barrel provided with four runners, Fig. 166, on which it rides when moving through the sewer, and carrying a water motor, the shaft of which extends out from the front end and carries a series of hook-shaped cutting blades. The motor is operated by water from a hydrant, delivered to one end of the cleaner through a fire hose. The cleaner is hauled through the sewer between manholes by means of windlasses and is said to have cleaned an 18-in. sewer 371 ft. long at a cost of $2.52 per foot. The apparatus is made by the Turbine Sewer Renovating Machine Co., of Milwaukee.

A description of the cleaning of sewers of heavy detritus is given by Frederick L. Ford in his annual report of 1905 as city engineer of Hartford, Conn. Sewers 3, 4 and 6 ft. in diameter, respectively, were cleaned, the first by the use of pails, and the second and third by the use of wheelbarrows. The length of sewer cleaned, the quantity of detritus removed and cost per load and per foot of sewer are given in Table 72.

TABLE 72.—DATA RELATING TO CLEANING LARGE SEWERS IN HARTFORD, CONN.

Size of sewer, ft	Length of sewer, ft.	Loads removed	Cost per load	Cost per foot of sewer
3	1916	107	$4.36	$0.243
4	2225	61	3.99	0.109
6	5128	107	3.62	0.075

The average distance cleaned per man per day was as follows: 3-ft. sewer, 9 ft.; 4-ft. sewer, 33 ft.; 6-ft. sewer, 32 ft.

The Thompson Sewer Cleaning Machine Co., of Buffalo, N. Y., has brought out the machine shown in Fig. 167. By using a snatch block at one end, the drawing cable can be slipped out of the block when the cable has reached the manhole, thus making it possible to pull up the scraper with its load and dump it into a cart or wheelbarrow. Such a scraper may be drawn backward and forward by means of hand windlasses or, upon large work, by hoisting or traction engines. If engines are used, great care should be exercised to prevent damaging the sewer by getting the scraper caught and then exerting undue pull upon the rope.

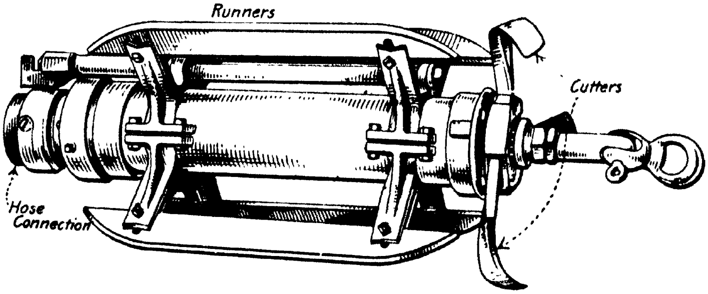


FIG. 166.—Turbine sewer cleaner.

An apparatus used for scraping sewers in the Borough of Brooklyn, New York, is illustrated in Fig. 168. The portable derrick is operated by a gasoline engine. The bucket and method of operation are described in a letter to the authors by E. J. Fort, Chief Eng. of Sewers, as follows:

"This bucket has been somewhat modified since it was first designed. It is fitted with a gate at each end, of the same design. This gate opens

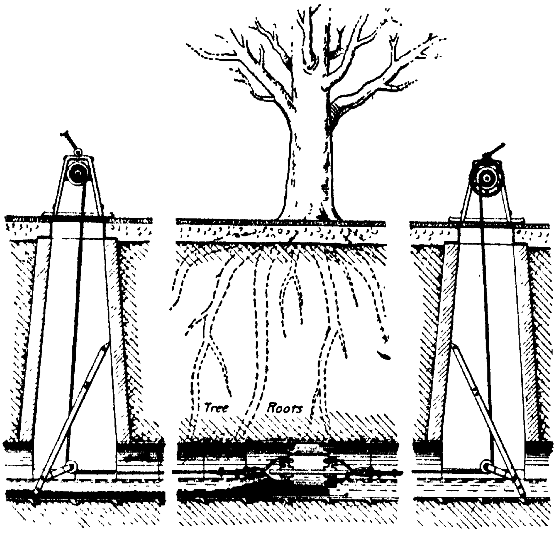


FIG. 167.—Thompson sewer cleaner.

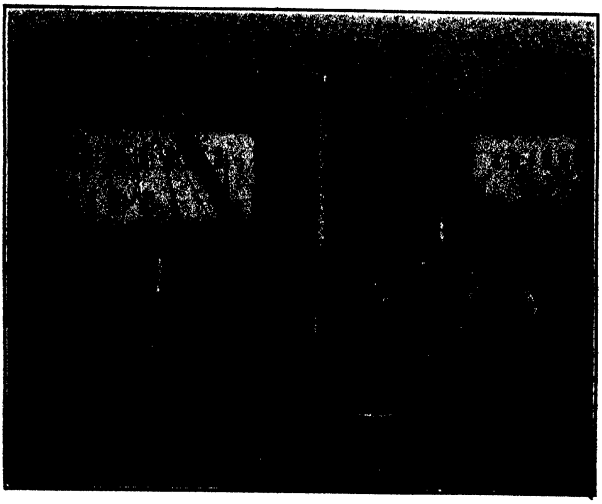


FIG. 168.—Brooklyn sewer cleaning equipment.

toward the inside of the bucket automatically. It opens outwardly when a latch is opened after it has been placed in position for dumping. . . . One man is stationed on the street at the manhole and guides the bucket in or out of the manhole as the engineer raises or lowers it. One man is located at the bottom of the manhole and throws the cable on or off a pulley as the bucket enters the sewer or leaves it. Two men who superintend the filling of the bucket carry it back into the sewer and place it in position for filling. The hoisting engine is then started and the bucket is allowed to scrape along the bottom until it is full. As it approaches the manhole where it is taken out, the cable is thrown off the pulley or snatch block and it is hoisted out of the hole."

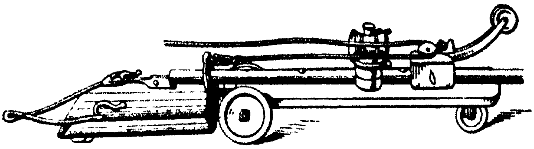


FIG. 169.—Healey sewer cleaning machine.

A scraper which has been used to some extent in the eastern part of the country, known as the Healey Sewer Cleaning Machine, is illustrated in Fig. 169.

Various other types of scrapers have been used, one of which is illustrated by Fig. 170. This scraper is provided with a rod connecting the two doors, so that when it is being pulled in one direction the rear door is held tightly closed and when being pulled in the other direction the opposite door is similarly closed. The difficulty with this and most other semicircular scrapers is to keep them right side up, as there seems to be a decided tendency for them to overturn. In this respect the full cylindrical scraper is perhaps somewhat more satisfactory. There is some tendency for all scrapers to ride over the deposit, especially if it is very much compacted or cemented with tar.

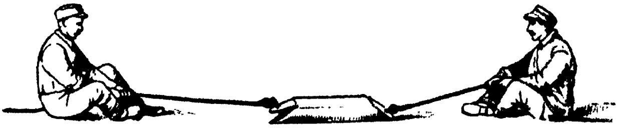


FIG. 170.—Scraper used at Quincy

Any sewer which is large enough for men to work in and in which the flow is not so deep as to prevent their standing on the bottom, can be most readily and economically cleaned by shoveling the deposit into buckets and handing them back from man to man, or shoveling it *directly into boats or placing the loaded buckets in boats and floating the load back to the manhole, through which it is to be removed.*

In some cases it has been necessary to clean relatively large sewers while they were in operation at nearly their full capacity. This has been successfully and economically done by means of full cylindrical scrapers hauled back and forth by hoisting engines.

It often happens that deposits are formed in relatively short lengths of sewers beyond which the grades are such as to provide self-cleansing velocities. In such cases it may not be necessary actually to remove the grit from the sewer, but simply to stir it up and flush it along to the point beyond which the velocity is sufficient to carry it to the outlet. Many devices for this work have been used, two of which are illustrated by Fig. 171.

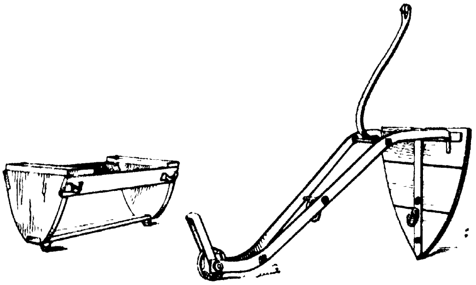


FIG. 171 —Flushers used at Newton.

Another device for accomplishing this purpose is a ball of slightly less diameter than the sewer. Such a ball is thrust into the sewer at the upper manhole and allowed to work its way toward the lower end. The natural flow of sewage is under and around the ball, scouring forward the deposit. This method of cleaning involves little expense and where conditions have been favorable, it has proved quite satisfactory. However, there is always some apprehension on the part of those in charge lest the ball become securely lodged in the sewer, causing a stoppage which will require digging it up.

Where sewers connect with intercepters leading to pumping stations and treatment works, there may be little gained by stirring up and flushing along such deposits. E. S. Dorr, head of the Boston Sewer Division for many years, has expressed the opinion that the use of scrapers with cutting edges for stirring up the deposit and carrying it along the sewer is not very practicable for that city, as the material is simply carried along to the intercepters or other places further down the line, from which it must ultimately be removed. For this reason, when the sewers are cleaned the material is generally taken out at the nearest manhole below.

One of the most useful tools for cleaning sewers is the jointed rod. Formerly the rods used for this purpose were made of 4-ft. lengths of 1/2-in. gas pipe threaded at each end. These pipes were taken into the manhole and coupled up as fast as they were pushed into the sewer. Later a much more convenient type of rod, with patent coupling for quick connection, has been used. Two types of such couplings are illustrated in Fig. 172. Both rods are made of wood, the couplings being securely attached to either end.

An idea of the kit of tools required by a sewer cleaning gang is given by Figs. 173 and 174, showing some of the tools used upon this work in Providence, R. I., from photographs kindly furnished by Allen Aldrich, Superintendent of Maintenance Dept. It will be noticed that most of the tools have been improvised for the work in hand, which will generally be found necessary, although there are a few stock articles, like cleaning rods and root cutters, which can be had from supply houses.

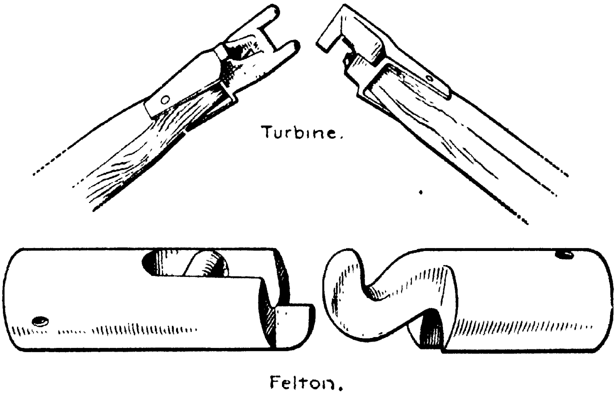


FIG 172.—Couplings for sewer rods.

A compilation of the number of miles of sewers and the cost of cleaning them in the Borough of Manhattan was given in *Municipal Journal*, vol. xxxviii, page 287, from which Table 73 was taken. It is interesting to note from a comparison of columns 2 and 3 of this table that there has been a very large increase in the proportion of the sewer systems cleaned. From 1886 to 1888 less than 5 per cent. of the sewers was cleaned, whereas in 1908 and 1909, between 40 and 50 per cent. of the total mileage was cleaned.

TABLE 73.—DATA RELATING TO CLEANING OF SEWERS IN THE BOROUGH OF MANHATTAN, NEW YORK

Year	Miles of sewers	Miles cleaned	Cost per mile	Year	Miles of sewers	Miles cleaned	Cost per mile
1886	414.20	10.6	$2,050	1898	484.35	43.8	640
1887	421.51	15.2	1,210	1899	489.05	44.4	1,520
1888	429.09	19.3	1,370	1900	494.57	56.6	980
1889	433.73	30.5	1,000	1901	496.94	66.2	980
1890	437.89	45.6	810	1902	500.59	85.6	690
1891	444.29	25.2	690	1903	505.08	124.5	470
1892	449.37	14.7	760	1904	507.64	132.6	470
1893	455.80	17.6	750	1905	511.36	99.7	660
1894	461.52	14.9	640	1906	513.77	144.8	510
1895	468.20	12.0	630	1907	517.97	205.6	490
1896	472.18	36.5	780	1908	521.67	218.7	440
1897	483.06	47.6	710	1909	523.34	248.8	360

The cost of removing deposit from sewers is generally very high because of the great difficulties under which the work is performed. Where the deposit consists of mineral matter and it is removed from small pipes, the work is necessarily slow, as the material has to be removed by scrapers unless it is possible to use some mechanical flushing device. Upon the larger sewers, where boats and pails may be used to advantage, the cost may be greatly reduced.

In Worcester, Mass., a regular cleaning gang is engaged upon work of this kind throughout the year, cleaning large and small sewers as necessity arises. During some winters additional help has been put on the cleaning of large sewers. The average cost per cubic yard of removing deposits from sewers, from 1903 to 1912 inclusive, has ranged from $3.88 to $9.74, as shown by Table 74. Obviously, the cost of removing material from small pipes has been much in excess of these figures and the cost of similar work upon large sewers has been materially less.

TABLE 74.—SEWER CLEANING IN WORCESTER, MASS.

Year	Miles of sewers in system	Quantity deposit removed, cu. yd.	Cost of removing deposit per cu. yd.
1903	169	1352	$6.56
1904	173	1393	4.89
1905	177	1484	3.88
1906	180	972	6.54
1907	183	665	9.74
1908	188	[1]909	5.84
1909	192	[1]825	7.28
✓1910	199	[1]580	7.82
1911	205	635	7.14
1912	213	728	5.35

[1] Including sediment removed from regulators.

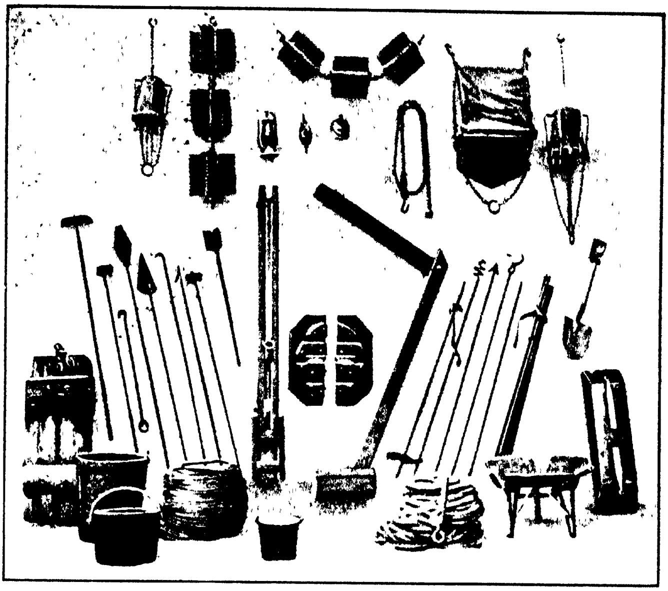


FIG. 173.—Providence sewer cleaning tools.

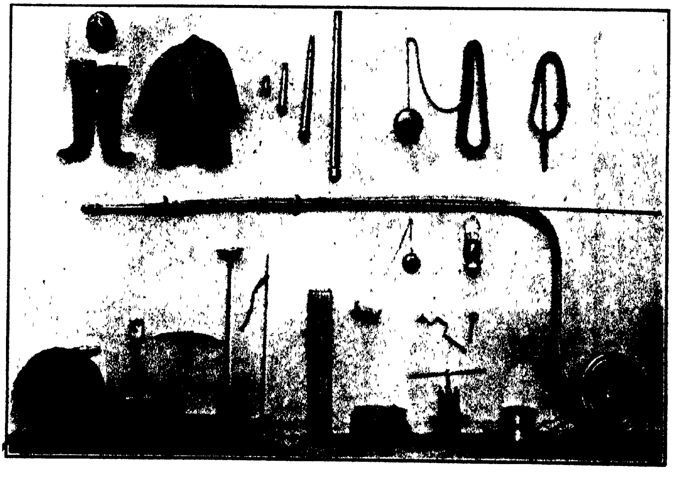


FIG. 174.—Providence sewer flushing equipment.

(*Facing page 508*)

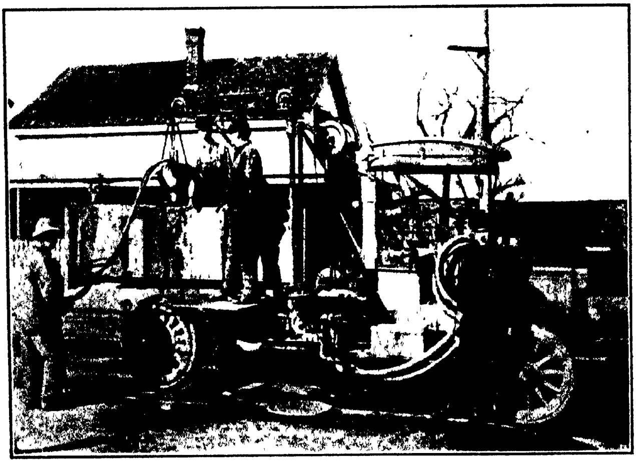


FIG 175.—Motor truck for cleaning catch-basins, Pawtucket.

Cleaning and Care of Catch-basins.—Most of the cities in this country provided with combined sewers or storm drains have built large numbers of catch-basins for retaining heavy road detritus, so that it will not enter the sewers and form deposits where the velocities of flow are relatively low. The care given to these basins varies greatly in different cities. In some places they are examined at frequent intervals and are cleaned whenever the deposit has accumulated to such an extent that their capacity is so reduced that they will not be likely to provide ample storage for the sediment to be deposited from one or more subsequent storms. In other cities, catch-basins are cleaned only when they are practically full. Still other maintenance departments do not attempt to clean basins until they are reported as being stopped, a condition indicated by the pooling or ponding of water in the gutters at the inlets.

Where catch-basins are cleaned only when they become stopped, or where the silt is allowed to accumulate in them to such a point that it will be carried over into the sewers, they become of little use, for the quantity of silt retained in them is usually only a very small proportion of the quantity entering them, the larger portion being carried over into the sewers. On the other hand, basins so cared for are objectionable as furnishing pools of stagnant water and filth, causing the escape of offensive odors and causing pooling of water in the gutters at the inlets. Therefore, it would seem preferable, if the basins are not to be properly cared for, to remove them altogether and substitute for them inlets discharging all silt directly into the sewers.

The quantity and character of material deposited in catch-basins varies according to the nature and slope of the surface of the street in which they are placed. Where the natural soil is of a sandy or gravelly nature, and slopes are steep and unpaved, large quantities of relatively clean sand and gravel are carried into the basin and are retained therein. Under similar conditions, if the soil is of a clayey nature, very little material may be deposited in the basin, as it settles so slowly that it is carried with the storm water through the basins into the sewers.

Where streets are paved, the quantity of material that is washed into and retained in the basins is relatively small and consists largely of organic matter, which becomes quite offensive as it undergoes putrefaction. The sandy deposits are usually relatively free from odor, and when the water is bailed out of the basins, they can be removed without creating objectionable conditions. If, on the other hand, the basins are in paved streets, the material remaining after bailing out as much water as is practicable is soft and offensive and cannot be thrown out on the street without causing objectionable conditions. Where deposits of the former are to be removed and the basins are of proper size, the most practical method is to have a man enter the basin and throw the material out of it onto the surface of the street. For such work two men should go together, one, the "bottom man," to do the work in the basin, the other to "bank off" the material thrown out and help load it into the cart. For economical work, several such crews should go together and be supervised by a foreman. Where three or more crews are working together, it will probably be wise to have two or more men precede the "bottom men," bailing out the water and getting the basins ready for them. Some of the material to be removed from the basin is soft and contains much putrid organic matter. It cannot be thrown out onto the streets during the busy working hours of the day. It may, under some conditions, be so handled during the night time. In some cities, however, it is found preferable to dip the material out of the basins with long dippers or pails, emptying it directly into carts.

Where material is thrown out onto the surface of the street, or where the basins contain putrid organic matter, the street should be thoroughly washed down and the basins filled with clean water and a liberal quantity of disinfectant sprinkled about to reduce to a minimum the offensive conditions.

At Pawtucket, R. I., the motor truck shown in Fig. 175 has been used in cleaning catch-basins. City Engineer Geo. A. Carpenter states that in 248 consecutive days in 1914, of which 208 were working days, the truck worked 113 days or 1071 hours. The four men employed with the truck are paid \$1.06$\frac{7}{8}$ per hour. During this time 821 of the 1151 catch-basins in the city were cleaned, some of them more than once. The total number of cleanings was 950. The truck removed 1474.62 cu. yd. of material, equivalent to 1.8 cu. yd. per basin cared for and 1.55 cu. yd. per basin cleaned. The haul was 500 to 15,000 ft. The truck can carry 2.6 cu. yd. The cost of the work was as follows:

Labor	$1,144.63
Gasoline	112.00
Oil and grease	14.70
Hydraulic oil	24.50
Tires	188.72
Interest	126.00
Depreciation	136.00
Total	$1,746.55

This amounts to \$1.185 per cubic yard. The tire expense is figured on the basis of a set of rear tires annually and a set of front tires every 2 years. The interest charge is 4 per cent. on \$4200 for 9 months. The depreciation is on the basis of 10 full years of work. If there were enough basins to keep the truck busy all the time, the cost of cleaning would be about \$1.20 per cubic yard, Mr. Carpenter estimates.

A marked advantage of the truck is its availability to respond instantly to emergency demands for catch-basin cleaning, and the work is done so easily that better cleaning results. "When a sudden and severe storm has visited the city," Mr. Carpenter stated, "our catch-basins have been able to take the water at each inlet and it has not run by plugged basins, as formerly, to reach low places which had no outlet, except through the sewers, with disastrous results. By assuring that the numerous inlets provided for storm water are kept clear and in working order, the capacity of the sewers has been increased, practically."

Much work is caused during the fall of the year by large quantities of leaves washed into the basins, in many cases causing clogging of the traps. This trouble will be reduced to a minimum by systematic, thorough cleaning of the streets during this time. While this involves some expense, it saves considerable cost caused by the accumulation of leaves in the catch-basins, and the net cost to the city may be no greater than if the leaves are allowed to be washed into the basins.

Another fruitful source of trouble is the freezing of basins during the winter. Where basins are connected with combined sewers, the air in the latter is usually warm enough to prevent freezing except where basins are located in very exposed localities. Where connected with storm drains, however, the air in the drains is not warm enough to prevent freezing, and much trouble has been experienced from this cause in a number of the northern cities, in some of which the number of basins frozen has been so large as to warrant providing portable boilers for furnishing hot water, which is pumped under pressure through a small flexible pipe into the basins and into the traps for thawing the ice. Such thawing is usually followed by placing salt in the trap to prevent further freezing. This precaution, however, is only serviceable until there is further run-off from the streets, after which another application of salt is necessary.

Basins containing large quantities of putrid or organic matter sometimes become quite offensive between storms. In such cases they should be flushed from a hydrant, thus changing the water, although if there is a large accumulation in the basins it will be better to remove it, afterward filling the basins with clean water.

Many different kinds of traps have been built in catch-basins, several of which are illustrated in Volume I. In selecting a trap, it is well to bear in mind that water standing above the deposit in the basin must be bailed out and discharged either into the street gutter, carried to a neighboring manhole or basin, or poured into a trap in the basin being cleaned. The last method is by far the most economical and satisfactory, and a trap suitable for such use should be provided.

The great quantity of detritus removed from the sewer systems of some cities is illustrated by data contained in Table 75, from a report of the Sewer Maintenance Department of Providence, for the year ending Sept. 30, 1913. At this time the population of Providence was about 235,000 and the total length of sewers was about 230 miles. During this year nearly 9000 catch-basins were cleaned and 18,233 cu. yd. of deposits were removed from them. A total of nearly 22,500 cu. yd. of deposit was removed from the trunk sewers and catch-basins. It is the practice to examine the basins once each month.

The data given in Table 76 afford a good idea of the amount of work involved in caring for catch-basins in a hilly city of moderate size, having a large number of streets built of gravel or water-bound macadam. Worcester has had a fairly uniform rate of growth and the sewer system has increased in size accordingly. This is reflected in the gradual increase in number of catch-basins. It will be seen that in a general way the basins average two cleanings annually. This is not strictly correct, however, as some basins which retain very little deposit are not cleaned oftener than once a year and others, located on or at the foot of steep hillsides, require cleaning frequently, sometimes as often as after each severe storm. The quantity of deposit removed from the basins has varied from 4 to 8.5 cu. yd. for every basin in the system. The average quantity removed at each cleaning is approximately 3 cu. yd. The increase in cost of cleaning in recent years has resulted largely from the

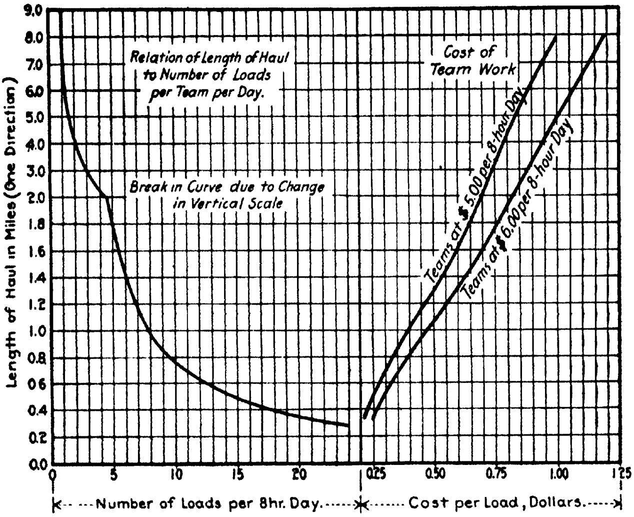


FIG. 176.—Effect of length of haul on cost of teaming in cleaning catch-basins.

TABLE 75.—WORK PERFORMED BY SEWER MAINTENANCE DEPARTMENT, PROVIDENCE, R. I., DURING YEAR ENDING SEPTEMBER 30, 1913

Months	Old work							New work										
	Old drains			Sand catchers		Open ditches			Sumps		Sewers				Catch basins			Total deposit removed, cubic yards
	Number	Length in feet	Deposit removed, cubic yards,	Number	Deposit removed, cubic yards	Number	Length in feet	Deposit removed, cubic yards	Number	Deposit removed, cubic yards	Number	Length in feet	Deposit removed, cubic yards	Dead ends	Number times examined	Number cleaned	Deposit removed, cubic yards	
October	2	570	37.62	...	...	3	1,685	62.40	29	308.26	67	20,350	43.39	60	Once	1,275	1,916.70	2,368.37
November	...	...	...	...	...	...	...	...	22	384 93	51	5,900	146.78	45	Once	879	1,431.18	1,862 89
December	...	...	...	...	...	1	150	100.00	25	266.82	20	6,000	38.89	...	Once	712	1,138.85	1,544.56
January	...	...	...	...	...	...	...	...	24	297.41	89	14,100	85.11	11	Once	539	1,134.37	1,516.89
February	...	...	...	12	60	1	1,462	52.15	22	156.37	70	16,600	125.63	70	Once	204	427.63	821.78
March	...	...	...	...	...	2	560	44 31	15	222.46	116	32,200	48.26	125	Once	501	1,274.31	1,589.34
April	2	480	29.76	...	...	1	100	14.00	21	258 22	19	4,960	22.07	...	Once	670	1,483.19	1,807.24
May	...	...	...	...	...	...	...	...	15	199 30	19	3,460	270.16	12	Once	780	1,967.47	2,436.93
June	...	...	...	...	...	...	...	...	14	204.85	42	9,100	27.45	5	Once	791	2,047.93	2,280.23
July	2	620	54.26	...	...	...	...	...	21	231.63	23	4,950	19.60	24	Once	882	1,922.05	2,227.54
August	...	...	...	12	60	2	500	31.63	10	158.56	37	7,600	23.00	...	Once	933	1,953.00	2,226.19
September	...	...	...	...	...	...	...	...	13	193.74	25	4,400	47.41	50	Once	696	1,536.44	1,777.59
Total	6	1,670	121.64	24	120	10	4,452	304.49	231	2,782.55	578	129,620	897.75	402	12	8,862	18,233.12	22,459.55

increased distance the refuse must be hauled to find a suitable dumping ground. The refuse is shoveled out of the basins onto the surface of the street, which accounts in a measure for the lower cost per cubic yard for doing this work in Worcester than in some other cities.

The effect of the length of haul on the number of loads per team per day and on the cost of team work in cleaning catch-basins is shown in the curves of Fig. 176, prepared from records of actual experience in Worcester, furnished by Matthew Gault, Superintendent of Sewers of that city. The records are based on an estimated average size of load of 1.2 cu. yd., weighing 3240 lb., and they cover a period of 87-1/2 team-days. They are representative of all work of this kind done in that city about 1907. The silt was the detritus from ordinary water-bound macadam; it was thrown out on the surface of the street by the bottom men and shoveled into ordinary tip carts.

TABLE 76.—NUMBER OF CATCH-BASINS CLEANED AND QUANTITY OF DEPOSIT REMOVED AT WORCESTER, MASS., 1902-1912

Year	Total number of catch-basins in system	Number of cleanings during year	Deposit[1] removed per basin per year, cu yd	Cost of cleaning per cubic yard deposit removed
1902	2526		8.5	$0.46
1903	2603	5549	7.9	0.41
1904	2694	5886	8.0	0.50
1905	2748		7.5	0.41
1906	2818	4652	6.5	0.57
1907	2902	4804	5.1	0.81
1908	3014	5053	4.6	0.81
1909	3138	5142	4.0	0.81
1910	3251	6094	4.9	0.74
1911	3322	7035	5.1	0.69
1912	3413	6783	5.1	0.85

[1] The total number of basins in system is used in computing this unit

Note.—The minimum wage was $1.85 for 8 hours from 1902 to 1911 and $2 in 1912. The "bottom man," however, was paid from $2.10 to $2.25 per 8-hour day. Teams cost $5 per day.

In *Engineering and Contracting*, March 23, 1910, there was published a table from the annual report for the year ending Dec. 31, 1909, of Edwin J. Fort, Chief Eng. of Sewers for the Borough of Brooklyn, giving data relating to the cleaning of catch-basins in that borough, which are reproduced in Table 77.

Relatively dry, clean deposits may be hauled from the basins to the dump in an ordinary tip cart with high sides. Special care should be taken to have the tail boards fit tightly so as to prevent the material from flowing through crevices and falling to the street. If the deposit is soft and wet, it is better to provide a tight cart with a cover, such as that shown in Fig. 177, of which several varieties of the same general type are on the market. Such carts are difficult to handle on soft dumps, where the wheels cut in, as they settle down so far that the body is likely to touch the ground and prevent convenient dumping.

TABLE 77.—CATCH-BASIN CLEANING IN BROOKLYN, N. Y., 1905–1909

Year	No of basins	No. examined	No. cleaned	Soil removed, cu. yd.	Cost per basin	Cost per cu yd.	No. cleaned of snow
1905	9,257	40,242	17,254	25,512	$1.79	$1.23	14,375
1906	9,537	49,768	25,386	33,423	1 65	1.25	5,999
1907	9,979	42,327	24,389	35,272	1 63	1.12	9,674
1908	10,127	47,933	30,693	44,476	1.60	1.10	5,423
1909 (11 mo.)	10,285	54,530	30,619	36,699	1.54½	1.35	5,615

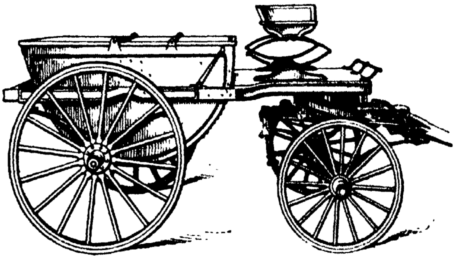


FIG. 177.—Covered tip-cart for catch-basin refuse.

TABLE 78.—COST OF CLEANING CATCH-BASINS IN AMERICAN CITIES, 1910

Frequency of cleaning	Cost per year			Cost per cleaning			Cost per cu.yd.			No. of cities represented
	Max	Min.	Mean	Max.	Min	Mean	Max.	Min.	Mean	
When full, necessary, or offensive	$10 00	$3.00	$5.00	$4 00	$0.20	$1.74	$1 00	$1.08	$1.34	21
After heavy rain	. .	.	.		.	..	...	.....	....	7
1-3 times per year ..	3.36	1.50	2 15	1 21	0 30	0 69	....	...	1.15	14
4-6 times per year...	4 50	3 36	4 03	.	...	0.40	....	.	1.15	8
7-9 times per year ...	. .	. .	1 34	..	...	..	. . .	.. .	.....	4
10-12 times per year.	..	.	.	. . .	. . . .		...	.	.....	5
More than 12 times per year..........	13 90	3.00	8 15	. .	...	.. .	.....	.....	.....	7
Total cities reporting.......	....	....	. ...	.. .	.			....	.....	66

The results of an inquiry made by *Municipal Engineering*, as to the practice of various cities in cleaning catch-basins, are shown in Table 78; 66 cities reported. It will be seen that 21, or practically one-third of the cities, clean the basins only when full or offensive. The average cost of cleaning per year varied from $1.34 to $8.15.

Recently the city of Washington has established the custom of thoroughly flushing out the catch-basins at intervals of two weeks, and then of dosing the contents of the basin with mosquito oil during the breeding season. The area of the water surface in the catch-basins, of which there are 5000, is approximately 12 sq. ft. each, and the quantity of oil applied to each basin at a single oiling is approximately 1 gill. The average cost of each treatment is said to be 6 cents, which of course does not include the cost of cleaning. The basins are regularly cleaned at intervals of four weeks throughout the year.

Repairs.—The repairs required by a sewer system depend on its age and the amount of such work done from year to year. One of the most common repairs is the changing of elevations of manhole covers. Covers placed to conform to a macadamized street are soon found to project above the surface because the pavement has worn. It soon becomes necessary, therefore, to lower the covers and when the street has worn to such an extent that it has to be rebuilt, it again becomes necessary to change the manhole covers, this time raising them to conform to the new elevation of the street. The cover illustrated by Fig. 238, Volume I, is designed to meet these conditions as economically as possible.

Catch-basins or inlets are frequently required before streets are paved or provided with sidewalks. When the streets are improved it is usually found that changes in grade and alignment require the alteration of the catch-basin inlets. While such changes and those affecting manhole covers must be paid for by the municipality, they form a fruitful source of contention between the different departments to determine which should more properly pay for the changes. Whatever decision may be reached in this matter, it is certain that the cost of such work should be carried as a separate item in the accounts.

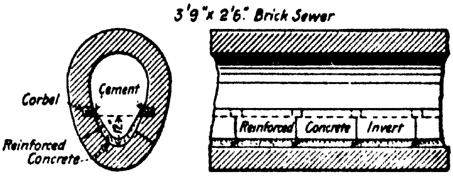
It will be found occasionally that brick and masonry sewers have become cracked or the inverts have become worn. Such minor repairs as are required to put the sewers into first-class condition should be made promptly. Little difficulty will be experienced in making repairs in the larger storm drains and in combined sewers. In the latter case, when the invert is to be repaired, the sewage must be dammed and carried over the section under repair in flumes or pipes. Diaphragm pump hose has often served for carrying sewage under such conditions and is particularly well adapted for this work.

The use of a cast lining for repairing the inverts of brick sewers at Hempstead, England, is described in the *Surveyor* for Aug. 16, 1912. The invert blocks were 2 in. thick and 2 ft. long. They were built of reinforced concrete, lowered through the manhole and laid in cement.

A corbel was placed on each side at the top of the invert and set into the original masonry. The offset formed by this corbel was smoothed back with cement mortar. Fig. 178 shows a cross-section of a sewer repaired in this manner.

Regulators and Inverted Siphons.—Where regulators are provided to control the flow of combined sewers into intercepters, they should be inspected at frequent intervals, preferably once each day, to make sure that they are in proper adjustment and in good working condition. The metal work should be carefully examined from time to time, worn parts removed, and if the parts are of iron they should be kept well painted with red lead and oil.

It was formerly thought that inverted siphons required much attention and cleaning, but this has proved incorrect in most cases. Such structures, however, should be examined at frequent intervals, preferably once each month, to make certain that they are in good condition, and if found to require cleaning or flushing they should be given prompt attention.



Cross Section. Longitudinal Section.

FIG 178.—Lining blocks for repairing sewer inverts.

Records.—It is very desirable that records be systematically kept in accordance with a general plan so laid out as to present the data in most convenient form and most easily accessible.

The form prepared by the Sanitary Section of the Boston Society of Civil Engineers for a Summary of Sewerage Statistics has been adopted in part by the Bureau of the Census of the U. S. Department of Commerce. It has also been adopted by a number of sewer departments and the data printed in their annual reports. A committee of the Sanitary Section of the Boston Society of Civil Engineers compiled data in accordance with this summary and presented reports, published in the *Journal of the Association of Engineering Societies*, vols. xl and xlii. A copy of the blank form, "Summary of Sewerage Statistics," omitting the portions relating to the details of sewage treatment, is given on pages 518 to 521 inclusive.

SUMMARY OF SEWERAGE STATISTICS

(In form recommended by Sanitary Section of Boston Society of Civil Engineers)

For the year ending .. ... ., 19 ....

....
(City or Town.) (State.)

Is this form used in preparing the annual report of your department?......

....
(Name, official title and address of person furnishing information)

General

Population by census of 19 . . ..

Total area of city or town .. . .square miles

Area served by sewerage system. .. . . “ “

Collection System { For sewage only . . ..miles

Collection System { For sewage and surface water. .... .miles

Collection System { For surface water only ....miles

Method of disposal . . . .

....

Collection

MAINS (EVERYTHING BUT HOUSE AND CATCH-BASIN CONNECTIONS)

	For sewage only	For sewage and surface water	For surface water only
1. Linear feet stone	....	....	....
2. “ “ brick	....	....	....
3. “ “ concrete. ...	....	....	....
4. “ “ pipe	....	....	....
5. “ “ extended during year	....	....	....
6. Number of inverted siphons . .	.. ....	....	....
7. “ “ manholes	.....	....	....

8. Method of flushing. .. ..

....

....

9. Method of cleaning .. ..

....

....

Collection.—*Continued*

	For sewage only	For sewage and surface water	For surface water only
10. Number of automatic flushing tanks			
11. Number of direct connections with water mains for flushing			
12. Number of flushings of entire system during year			
13. Cost of flushing per mile			
14. Number of miles cleaned			
15. Cost of cleaning per mile			
16. Number of stoppages			
17. Miles of permanent underdrains			
18. Number of storm overflows			
19. Method of ventilation			
20. Cost of maintaining sewer system exclusive of disposal works (including cost of flushing and cleaning sewers; cost of cleaning catch-basins; administration and unclassified expense)			
HOUSE CONNECTIONS			
21. By whom made			
22. Sizes			
23. Number made during year			
24. Linear feet laid during year			
25. Linear feet discontinued during year			
26. Total miles in use			
27. Average cost per ft., connections made during year			
28. Number of stoppages coming to attention of department			

CATCH-BASINS

29. Number . . . .
30. Number cleaned . . . .
31. Av. amount material removed per catch-basin . . . .
32. Cost of removing material per cubic yard . . . .
33. “ “ “ “ “ catch-basin per year . . . .

Discharge of Sewage

34. Estimated population using sewer system . ...
35. Number of buildings connected . . . .

	Average (gallons)	Maximum (gallons)	Minimum (gallons)
36. Daily discharge for year .	......	....	....
37. " " " each user .	....	....	....
38. " quantity of factory waste	.....	....	....
39. " leakage into sewers . . .	.....	......	....
40. " " per mile of sewer	.....	....	....

41. Are quantities given under 36 and 38 estimated or measured?........
....

Pumping

42. Description of plants . . ..
....
....
....

43. Description of fuels or power used:—
  A. *Coal.*
    (*a*) Kind . . . .
    (*b*) Brand. . . . .
    (*c*) Av. cost per gross ton delivered . . . . . $...............................
    (*d*) Percentage of ash. . . . .
  B. *Fuel for internal combustion engines.*
    (*e*) Kind and grade . . . .
    (*f*) Av. cost . . . . $...............................
  C. *Electricity.*
    (*g*) Av. cost per kw. hr. . . . $...............................
44. Amount of fuel or power consumed for the year... ....
45. Total pumpage for year with / without allowance for slip...............gals.
46. Av. static head against which pump works........ .... ft.
47. Av. dynamic head against which pump works........ ....ft.
48. No. of gallons raised one foot per unit of fuel or power ....
49. ✓Cost of pumping figured on pumping station expenses per million gallons raised one foot (dynamic), not including fixed charges . $...........
50. Describe screens..
....
....

Financial

CONSTRUCTION

Receipts

86. Balance of previous year . . . . $. . . . .
87. Bonds issued . . . .
88. Appropriation. . . . .
89. Assessments. . . . .
90. House connections. . . . .
91. Other sources . . . .

92. Total, $. . . . .

Expenditures

93. Collection works:
    (*a*) mains. . . . . . $. . . . .
    (*b*) house connections . . . .
94. Disposal and purification works . . . .
95. Balance . . . .

96. Total, $. . . . .

MAINTENANCE AND OPERATION

Receipts

97. Balance of previous year . . . . $. . . . . . .
98. Appropriation . . . . .
99. Assessments . . . .
100. Rentals . . . .
101. Other sources . . . . . .

102. Total, $. . . . .

Expenditures

103. Administration . . $. . . . .
104. Repairs[2] . . . .
105. Cleaning sewers . . . .
106. " catch-basins . . . .
107. Flushing sewers . . . .
108. Pumping . . . .
109. Disposal or purification[1] . . . .
110. Unclassified expenses[2]. . . . .
111. Balance. . . . .

112. Total, $. . . . .

113. Interest on bonds . . . .
114. Sinking fund . . . .

GENERAL

115. Total cost of collecting mains . . . . $. . . . .
116. " " " pumping system . . . .
117. " " " disposal works. . . . .
118. " " " works to date. . . . .
119. Bonded debt at date . . . .
120. Value of sinking fund at date . . . .
121. Average rate of interest on bonds. . . . . .per cent.
122. Proportion of cost of system assessed on abutters.. . . . .
123. Yearly assessment for maintenance . . . .
124. Method of assessing abutters and rate of assessment . . . .

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[1] Including payment for maintenance of joint disposal works.

[2] State what "Repairs" and "Unclassified expenses" include.

While it is not to be expected that all sewer departments will incorporate this summary of sewerage statistics into their annual reports, it is very desirable that they begin, if possible, to keep their records in such form that they will provide the data required for this summary, particularly in view of the fact that the information is called for by the Bureau of the Census.

Cost of Operation and Maintenance of Sewerage Systems.—The cost of operation and maintenance of a sewerage system will depend upon its extent, age, the number of special features such as catch-basins, inverted siphons, automatic regulators, tide gates and pumping stations; the character of design and construction; the topography, character of soil and extent of development of the community; the attention given to the care of the works; the degree of efficiency of the several features of the system; and the efficiency of the operating and maintenance organization.

It should not cost much to maintain a sewer if it is allowed to go completely out of use, as has been the case in some instances known to the authors. One such instance was an intercepting sewer which had been allowed to become partly filled with detritus. Finally a hole was broken in it near its upper end. The sewage was collected from about one-half the city and allowed to find its way against the grade of the intercepter, out at the upper end into the river, and then finally flow downstream past the city, a condition which the intercepter, built at an expense of over $160,000 was intended to prevent.

The most complete records of maintenance with which the authors are familiar, covering a long period of years, have been printed in the reports of the Superintendent of Sewers of Worcester, Mass., and the data from this source in Table 79 cover the period from 1877 to 1912 inclusive. It is not practicable to give sufficient information about the Worcester sewerage system to enable the reader to understand in detail the meaning of these expenditures, but a few notes may enable him to use the data as a guide in preparing similar statistics and to make rough but helpful comparisons.

This system was originally built upon the combined plan without pumping stations and discharged at numerous points into Mill Brook, a creek of about 3,000,000 gal. daily dry-weather flow, largely drawn from storage. The general topography is moderately rugged, although slopes in excess of 5 per cent. are rare and there are many lines of sewers laid on flat grades. The soil varies in character in different parts of the city, including sand, gravel, loam, and hardpan. In 1912 there were 23.54 miles of paved streets, 76.38 miles of water-bound macadam, and 113.97 miles of natural earth or gravel streets, making a total of 213.89 miles. There were 213.09 miles of sewers and storm drains. About 1890 the city began the construction of separate sewers and storm drains in certain portions of the city, continuing the construction of combined sewers in others. In 1897 work was begun on intercepting sewers and the paralleling of combined sewers with separate sewers in a large area comprising about one-third of the sewered portion of the city. At the close of the year 1912 there were 13 inverted siphons, 32 automatic regulators, 3413 catch-basins and 7528 manholes. The lengths of sewers and drains were:

Separate sewers	93.320 miles
Combined sewers	66.053 miles
Storm drains	53.714 miles
Total	213.087 miles

There are now four small pumping stations, two using centrifugal pumps and two Shone ejectors.

The cost of maintenance of the sewer system for each year from 1877 to 1912 inclusive covers the cost of cleaning sewers, catch-basins, inverted siphons and regulators, of keeping the entire system in repair, of readjusting manholes and catch-basins to conform to lines and grades of streets as required by construction and reconstruction by street department, of operation of pumping stations, regulators, etc. The system of accounts has been so kept for about 15 years that the Sewer Maintenance Department has borne its proper portion of the main office and overhead charges. The repairs to sewers, when in the nature of upkeep, appear in the maintenance account but when reconstruction is necessary it is charged to construction.

At the end of 1912 the books showed the cost of the system to be $5,400,791.21 equivalent to about $25,350 per mile.[1] The maintenance cost, including pumping, for that year was $29,744.78, equivalent to to 0.55 per cent. upon the book value. If the cost of pumping and alterations due to changes made by street department and a small sum paid in damages are omitted, the true maintenance cost, *i.e.*, for repairs and cleaning, would become $22,002.57 equivalent to 0.4 per cent. of the book value.

The annual sums expended upon strictly maintenance work from 1902 to 1912 inclusive are given in Table 80, from which it will be seen that the cleaning of catch-basins is by far the largest item.

To arrive at a clear conception of the meaning of these expenditures, they have been reduced to units of cost per mile of sewers and drains, per catch-basin and per regulator, Table 81. With the increase in the proportion of separate sewers, there has been a reduction of cost of cleaning, because the removal of sand and road detritus is only necessary from the combined sewers and storm drains, the separate sewers simply

[1] Including the construction of a stone masonry conduit for Millbrook, the lower portion of which is 13 × 18 ft.

requiring flushing. As only a very few miles of sewers require cleaning, these costs, if reduced to units per mile of sewer actually cleaned, would be very high. The cost of cleaning catch-basins is largely dependent upon the distance the refuse must be hauled for disposal, which in the larger cities is likely to gradually increase as the natural dumps become filled. It should be noted that the cost of catch-basin cleaning has

TABLE 79.—TOTAL AND UNIT COSTS OF MAINTENANCE AND OPERATION OF SEWERAGE SYSTEM AT WORCESTER, MASS., 1877–1912

Date	Miles sewers and drains	Net expenses	Cost per mile
1877	36.17	$7,775.44	$214.97
1878	37.26	6,657.59	176.26
1879	37.38	6,307.16	168.73
1880	37.88	6,937.43	183.14
1881	40.40	6,379.10	157.90
1882	42.90	7,490.01	174.59
1883	45.63	8,421.88	184.56
1884	48.00	9,132 05	190.25
1885	50.94	8,656.86	169.94
1886	56.41	10,843.23	192.22
1887	62.89	12,819.53	203.84
1888	68 02	12,989.12	190.96
1889	71.39	13,995 65	196.04
1890	76.59	14,686.38	191.75
1891	80.94	13,435.66	165.99
1892	85.44	13,488.24	157.86
1893	90.04	15,423.38	171.29
1894	95.42	16,302.97	170.85
1895	99.29	17,518.17	176.43
1896	102.69	15,925.38	155.08
1897	112.01	14,504.06	129.48
1898	121.97	13,475.08	110.47
1899	134.14	16,234.00	121.02
1900	151 09	19,488.55	128.98
1901	158 47	19,730.69	124.50
1902	162.75	22,715.75	139.57
1903	169.13	26,300.89	155.51
1904	172 97	26,962.84	155.88
1905	176.81	27,973.29	158.21
1906	179.56	30,063.50	167.42
1907	183.04	29,999.02	163.89
1908	187.73	29,084.42	159.43
1909	192.25	30,645.92	159.41
1910	198.66	29,326.99	147.62
1911	205.32	29,729.91	144.80
1912	213.09	29,744.78	139.59

Table 80.—Itemized Total Costs of Repairs, Changes, Cleaning Sewers, Cleaning Catch-basins and Maintaining Automatic Regulators at Worcester, Mass., 1902–1912

Year	Repairs of sewers, catch-basins, manholes and other structures	Changes[1] in manholes and catch-basins	Cleaning sewers	Cleaning catch-basins	Maintaining regulators	Total
1902	$4,879	....	$7,356	$12,146	$ 130	$24,511
1903	5,355	....	9,019	8,414	41	22,829
1904	4,646	1,110	6,802	10,845	1,162	24,565
1905	5,917	876	5,754	8,390	1,718	22,655
1906	5,634	1,122	6,391	10,360	2,407	25,914
1907	4,553	700	6,478	11,908	2,480	26,117
1908	4,142	558	5,306	11,118	3,188	24,312
1909	3,995	1,047	6,007	[2]10,101	2,062	23,212
1910	660	3.533	4,535	[2]11,527	1,988	22,243
1911	2,040	1,918	4,533	[2]12,334	1,729	22,554
1912	1,366	1,161	3,899	[2]14,829	1,909	23,164

[1] Changes due to alterations in street lines and grades by street department.

[2] Includes costs of freeing traps—$104, $495, $694 and $1603 for years 1909 to 1912, respectively.

Table 81.—Itemized Unit Costs of Repairs, Cleaning Sewers Cleaning Catch-basins and Maintaining Automatic Regulators at Worcester, Mass., 1902–1912

Year	Repairs of sewers, catch-basins, manholes and other structures per mile of system	Cleaning sewers per mile of system	Cleaning catch-basins per basin[1]	Maintaining regulators per regulator
1902	$30	$45	$4.81	$4.06
1903	32	54	3.23	1.28
1904	27	39	4.03	36.31
1905	33	33	3.06	53.69
1906	31	36	3.68	75.22
1907	25	35	4.10	77.50
1908	22	28	3.69	99.62
1909	21	31	3.22	64.44
1910	3	23	3.55	62.13
1911	10	22	3.71	54.03
1912	6	18	4.35	59.66

[1] Based on whole number of basins and not on number actually cleaned.

ranged from $3.06 to $4.81 per basin per year. While these costs are greater than they would be in cities where grades are less steep and the soil of such a nature that it will not be retained to so great an extent in the catch-basins, nevertheless the probable cost of such cleaning is one of the things which should be carefully considered before deciding whether to put in catch-basins or direct inlets. In some cases it may even be wise to take out existing basins.

From the footnote to Table 80 it will be seen that the cost of keeping catch-basin traps free from obstruction, largely ice, is considerable.

The cost of cleaning catch-basins per cubic yard of material removed from 1909 to 1912 ranged from $0.70 to $0.80, exclusive of cost of freeing traps. The average annual cost of cleaning the sewers, per cubic yard of material removed, during the last ten years has ranged from about $4 to nearly $10, the range in cost of cleaning individual sewers being much greater, however. It is evident that it is much less expensive to remove material from the catch-basins than from the sewers. Similarly, it will be found far less expensive to remove sand and detritus from the street gutters than from the basins. Therefore in places where detritus will settle and accumulate in sewers, it may be economical to use catch-basins and it will be economical to make every effort to keep the streets clean that the quantity of detritus to be removed from basins and sewers may be reduced to a minimum. Catch-basins should be put in only as a result of careful and intelligent consideration of all local conditions.

CHAPTER XIX

EXPLOSIONS IN SEWERS

Explosions in sewers, which occurred at rare intervals for many years, have recently become common occurrences. The disastrous results of some of them and an appreciation of the serious character of this source of danger is leading to much study of their causes and methods of preventing them.

Sources of Inflammable Gases and Explosions.—Many explosions have occurred in sewers, due to the ignition of explosive mixtures of air with illuminating gas, naphtha vapor or possibly other gases. Illuminating gas leaking from a defective main may find its way through the ground and into a sewer in sufficient quantity to cause an explosive mixture. Most sewer maintenance superintendents have had experiences of this kind, although probably in relatively few have there been explosions. It is not always easy to find the source of such gas, as it may travel a considerable distance from the point where it enters the sewer to the place where it is detected. During recent years trouble has frequently resulted from the discharge of gasoline into sewers, largely from automobile garages. Gasoline vapor is considerably heavier than air and therefore is not always readily distinguished by odor when the observation is made from the top of the manhole. This new source of danger has necessitated ordinances preventing the discharge of gasoline into sewers and requiring lighting appliances for the use of inspectors and laborers while working within the sewers.

An explosive mixture may result from the decomposition of the organic matter in the deposits. By such decomposition marsh gas, or methane, may be produced in considerable quantities, and if there is not an adequate circulation of air to provide ventilation, it is conceivable that the proportion of this gas to the oxygen in the air in the sewer may be sufficient to provide an explosive mixture. While it must be acknowledged that this is a possibility in a few badly ventilated sewers in which extensive deposits of organic matter are present, experience leads to the conclusion that this can be the cause of explosions in very few cases.

In a paper entitled "The Discharge of Inflammable Wastes into Sewerage Systems and the Problem of Prevention," by N. S. Sprague, Superintendent of the Bureau of Construction, Department of Public Works, Pittsburg, presented to the annual convention in 1914 of the

American Society of Municipal Improvements, he points out a possibility of the leakage of gasoline from storage tanks which are placed underground, usually pursuant to requirements of municipal ordinances; this gasoline may find its way into sewers. Furthermore these tanks are often laid directly on the ground and covered with earth, under which circumstances erosion, breakage of joints and even electrolytic action may result in leakage.

Waste inflammable liquors are discharged in small quantities from many households, private garages, stores and shops, but the greater danger probably arises from the discharge of much larger quantities of such liquids from public garages, dry-cleaning establishments, paint works, oil refineries, gas works and other industrial establishments. Mr. Sprague points out that prior to the use of motor vehicles there were many industrial and business establishments using inflammable and volatile wastes, such as dry-cleaning shops, paint manufactories and gas works, and that notwithstanding this fact, explosions in sewers caused by the ignition of gasoline or other similar vapors were uncommon. This fact, he concludes, would seem to indicate that the great increase in the use of gasoline due to the rapidly increasing numbers of motor vehicles has been responsible for many of the recent sewer explosions, a conclusion in which most, if not all, recent investigators of this problem appear to concur.

Summarizing the investigations which have been made, it appears that explosive mixtures in sewers are most likely to be caused by inflammable liquids, of which gasoline is a type and the one most commonly encountered; that natural or artificial gas undoubtedly has been a cause of some explosions; and that in rare instances marsh gas, or other similar gas, may be generated in the organic deposits in sewers in sufficient quantities to produce explosive mixtures under certain conditions.

Pittsburg Explosion.—On Nov. 25, 1913, probably the most disastrous sewer explosion up to that time occurred in Pittsburg. A detailed account of this accident was printed in *Engineering News*, Jan. 1, 1914. In this case the main trunk combined sewer serving a population of 50,000 and varying in diameter from 8 to 10 ft. was disrupted, more or less completely, for a distance of 5300 ft. The damage included the destruction of brickwork and manholes, breaking of windows in factories, caving in of streets, and damage to laterals leading to the main sewer at many points. At the time of the explosion the outlet, which was nearby, was submerged to within 1-1/2 ft. of the top. It is estimated that 90 per cent. of the public garages of the city are located within the tributary area of this sewer as well as a number of dry-cleaning establishments and paint manufactories. This explosion cost the city down to October, 1914, about $300,000, which may be increased by decisions in possible damage suits. A second but less disastrous explosion occurred in this sewer on July 28, 1914. That this explosion was caused by ignition of a mixture of air and gasoline vapor seems well established, for on the day it occurred city employees were working in the sewer, and, when a strong odor of gasoline was noticed were ordered out of the sewer only 15 minutes before the explosion occurred (*Eng. Record*, Aug. 8, 1914).

New York Explosions.—A series of spectacular explosions in New York on Oct. 7, 1909, was described by A. A. Breneman in *Engineering News*, Dec. 2, 1909. At 4.40 P. M. there was a violent explosion in the sewer at 48th St. and 10th Ave. A few seconds later, there was an explosion considerably farther south in 10th Ave., following which there was a series of explosions, some running continuously for distances along 10th Ave. or the intersecting side streets, and some separated by considerable intervals of time. Roughly, the explosions are said to have affected an area more than a half mile square and probably lifted over a hundred heavy iron covers.

Upon investigation Mr. Breneman reached the conclusion that illuminating gas did not cause these explosions. In discussing the probability of vapors from volatile liquids as the cause, he stated that there were many garages in the region adjacent to the explosion area, and while at each garage more or less gasoline was stored in tanks in such a way as to prevent any leakage from them into the sewers, gasoline was used extensively in washing machinery about the vehicles, for dissolving heavy oils adhering to them, and for washing the hands of hundreds of employees. It was also used where heavy oils had to be removed from floors or other parts of the building. The difficulty of disposing of this impure gasoline except by way of the street gutters or sewers was obvious. About one week after the explosion an inspection of the sewers in which the accident occurred disclosed the odor of gasoline in all but one of the manholes opened. During these explosions in all cases the burst of flame from the manhole was followed by dense black smoke, indicating a volatile oil, because such smoke would not be produced by mixtures of illuminating gas and air. The conclusion, therefore, seemed to be justified that these explosions were due to gasoline vapor.

Another explosion occurred in a sewer on Sept. 21, 1914, being the third in that vicinity within a year. This explosion appears to have been caused by the ignition of an explosive gas within the sewer by sparks from the underground conduit of the street railway on 42nd Street. This conduit, carrying the electric conductor, is connected to the sewer by drains, and it is through these openings that the explosive gases are assumed to have made their way into the conduit, in which they are thought to have been ignited by electric sparks from the conductor in the conduit, from which the cars obtain their current.

New Haven Explosions and Investigations.—H. J. Kellogg, Assistant City Engineer, New Haven, Conn., carried on investigations for about a year to determine the causes of, and to find means for preventing, explosions in sewers. He reported some of the results of these investigations in a paper abstracted in *Engineering and Contracting*, vol. xli, page 250, from which the following notes and comments are taken:

> In 1886 there was an explosion in a New Haven sewer 60 in. in diameter. The arch was thrown completely off for about 100 ft. No one knows what combustible wrought the destruction, nor how it was ignited. No one was injured. About 1894 a 54-in. circular brick sewer was being cleaned by four men when an explosion occurred. The men escaped with difficulty, two of them being disabled for six months or more. The cause of the explosion appears to have been illuminating gas ignited by lanterns which the men carried. In 1913 a 42-in. egg-shaped brick sewer in New Haven was being cleaned when an explosion occurred, burning the men about their hands and faces. The cause of this explosion does not appear to have been definitely ascertained, although a slight odor of gasoline was noticed before the men entered the sewer. If gasoline was the cause of the explosion it probably came from a manufacturing plant, the drain from which entered the sewer close to the point at which the explosion occurred. Very small quantities of gasoline were used at this plant.

At Philadelphia an explosion in which several men were injured was attributed to gasoline vapor. Mr. Kellogg quoted from a letter from George S. Webster, Chief Eng., Bureau of Sewers, as follows:

> "A suspicious smell was noticed upon opening a sewer manhole, and a blazing paper thrown in resulted in a column of flame, about 40 ft. in height, due to gasoline from a nearby factory."
>
> Two men were killed in a Philadelphia sewer explosion about 1912. The cause is said to have been illuminating gas from a leaky main which ran parallel to the sewer. At a later date a man was burned by an explosion resulting from gasoline discharged from a dry cleaning shop.
>
> Explosions in sewers were reported from Providence, R. I., Buffalo, N. Y., Washington, D. C., Fall River, Mass., Detroit, Mich., Brooklyn, N.Y., Cleveland, O., Worcester, Mass., St. Paul, Minn., Kansas City, Mo., Duluth, Minn., Los Angeles, Cal., Savannah, Ga., Baltimore, Md., Hartford, Conn., New Haven, Conn., Pittsburg, Pa., San Francisco, Cal., Louisville, Ky., and Charleston, S. C.

The cause of explosion in a majority of these places was reported as illuminating gas.

George H. Norton, Deputy Engineer Commissioner, Buffalo, N. Y., described a new gas found in sewers as follows:

> "It may be interesting to know that for three years past at periods following thawing weather, after frost and heavy snow, we have had serious complaint from gas odor in some of our sewers. This has been traced down

and found to be due to the use, by the railroads, of what is called a hydrocarbon oil, which is used by them to prevent freezing of their switches and interlocking plants in their passenger station yards, and at other congested points. An examination was made by the city chemist and he reports that at low temperatures this oil will crystallize, that such crystals are soluble in water, and for this reason he thinks that the odors or gases have passed the ordinary vent sewer trap. The gases arising from this oil are, apparently, highly explosive and could readily be the cause of a serious explosion. This oil is a by-product from the Pintsch gas product used for car lighting."

Roscoe M. Clark, City Engineer of Hartford, Conn., gave the following information:

"I have no recollection of any explosions in the sewers previous to 1913. In 1913 we had two serious explosions in the Park River intercepter. The first, occurring in January, lifted one manhole head and threw several covers in the air, and also shattered windows in adjoining houses. The second occurred in May when the East side Pumping Station and its connection with the Park River intercepting sewer were in process of construction. The most damage was done to the station and adjoining houses. Both of the explosions took place in the vicinity of the works of the Hartford City Gas Light Company. Suits brought by property owners and the contractor for the pumping station are now pending in court."

Robert Adamson, Fire Commissioner of the Borough of Manhattan, New York City, reported that there were eleven sewer explosions between June 5, 1912, and the date of his letter, probably about a year later. He stated that the probable causes of explosion in New York are gasoline, illuminating gas, and calcium carbide. He stated further that prior to the regulation requiring the installation of oil separators in garages, the majority of sewer explosions was limited to what is known as the "garage zone." Since their installation the number of explosions has been greatly reduced. The following quotation is from Mr. Adamson's letter:

"The illuminating gas enters the sewer from ruptured, corroded or broken gas mains, or from leaky joints, and when mixed in the proper proportions with air forms an explosive mixture. Calcium carbide, which is used in garages for generating lights, may be thrown into the sewer and when in contact with water generates acetylene gas, which is an intense explosive and is further auto-combustible, so that in many instances it may be ignited by its own heat generated in evolving the acetylene. The vapors of gasoline and illuminating gas require an open flame to ignite them, but whether this occurs in sewers it is impossible to tell. In vaults and in conduits the igniting spark is furnished in a number of cases by electrical apparatus, such as switchboards, sump pumps, short circuiting, etc. Some relation exists between sewer explosions and flooding of the sewers, and further when the sewers become tidebound these explosions are more frequent, such as following an unusual shower of heavy rain or a fall of snow or thawing of ice.

This causes a condensation of the gases within the sewer. There are no casualties on record resulting from these explosions but considerable damage to property often occurs. In relation to places where oil is stored, the oil separator is the only method at present under the regulations of preventing volatile inflammable oil from discharging into the sewer."

Mr. Kellogg stated that one volume of gasoline oil produces 141 equal volumes of gas or vapor, as figured by Prof. A. L. Dean, who gave as the computed best mixture for complete combustion: 1 part of gas to 62-1/2 parts of air. In gas engines, especially in automobile driving, an excess of air is said to give better practical results. The following figures lead up to a knowledge of the amount of gas likely to be in a sewer from a given amount of oil: 1 gal. gasoline gives 141 gal. of gas; 141 gal. gas equals about 18.8 cu. ft. of gas; 18.8 cu. ft. of gas with 1175 cu. ft. of air, best explosive mixture. There is a broad variation in the proportions of this gas and air that will form combustible mixtures. Now allowing 8 cu. ft. as the available space for 1 lin. ft. of a 42-in. sewer in New Haven, 1 gal. of gasoline could have furnished a prime mixture for about 150 lin. ft. of that sewer. A leaner but still dangerous mixture might more than double the danger zone. Although the rate of flow in the sewer, the time it would take to vaporize the oil, the draft in the sewer and perhaps other factors, complicate the problem, the above figures show that a comparatively small quantity of gasoline is capable of making trouble. Mr. Kellogg also stated that about 1 part of illuminating gas to about 7 parts of air is computed to be the best mixture for complete explosive combustion.

Boston Explosion.—A fatal explosion occurred on June 1, 1914, at the Chelsea Street pumping station of the sewerage system of the Metropolitan Water and Sewerage Board, Boston, Mass. This explosion occurred in the screen house which adjoins the pumping station. The screen house was wrecked, the brick walls being blown out and the reinforced concrete and tile roof being blown to pieces. The pumping station was badly damaged and three of the four pumps were seriously injured. The explosion caused the death of six men and the serious injury of three others. Early estimates placed the property damage at about $50,000. The explosion is said to have been caused by gasoline vapor which it has been suggested may have been present in greater quantity than usual because of the large amount of work done in automobile garages during Memorial Day and Sunday, the two days preceding the explosion. (*Engineering News*, June 4, 1914.)

Behavior of Gasoline in Sewers.—A study of gasoline explosions in sewers was made in August, 1914, for the consulting engineer of the Borough of Manhattan, E. P. Goodrich, by O. Hufeland, assistant engineer in the sewerage division of the Borough. A review of all of the available evidence led to the conclusion that one volume of gasoline will produce from 141 to 171 volumes of vapor. This vapor begins to form an explosive compound with air when the mixture contains 1.2

per cent. of vapor, or perhaps a little less. In such a mixture a flame will apparently just travel along. With a 1.5 per cent. mixture the flame travels much more rapidly and burns brightly. With 2 per cent. of vapor, the movement becomes so fast that the combustion will be explosive and this increases until the amount of vapor in the mixture is about 2.6 per cent. The violence of the explosion decreases as the amount of vapor increases, and when about 5 per cent. of vapor is present, the mixture apparently burns quietly and there is little danger of an explosion. No record of spontaneous combustion has been found, but very slight sparks will cause an explosion of mixtures containing certain proportions of vapor. For instance, investigations of alleged spontaneous explosions in dry cleaning establishments have shown that the spark was caused by the friction of the materials in the tank of gasoline. One example of this occurred when the materials in the tank were wool and silk, and another instance when leather was being treated. The addition of a little soap to the gasoline removed the danger apparently.

The only instances of serious destruction of sewers, caused by explosions of this nature, which Mr. Hufeland could find, were in Manhattan in 1906, and in Pittsburg in 1913, already described in this chapter.

Sewer explosions generally consist of a series of upheavals of manhole covers, which are blown out with measurable periods of time between the explosions at successive points. An explanation of this condition is that the vapor does not collect in large amounts at any one point and that when it is ignited its explosive force is slight and the flame follows along the course of the sewer, without doing much damage.

The gasoline vapor is heavier than air and accordingly tends to accumulate over the surface of the flowing sewage. Its weight will also tend to make it flow downward with the sewage, toward lower levels, and if these are outlets, the vapor will escape into the open air there, provided the outlets are not trapped by the rise of tide or some equivalent. An element of danger is introduced into such a condition by the possible presence of illuminating gas. This tends to rise, and if present in a quantity making a combustible mixture with the air in a sewer, it might lead a flame, if it were ignited, back to the explosive mixture of gasoline vapor and air. It is also suggested that methane might have some influence on such explosions. Mr. Hufeland reports that it is rather frequently found in Manhattan in small quantities in pockets in which sediment has decomposed, which when stirred up by a passing workman gives off gas that has occasionally flashed up and singed the hair and eyebrows of the man, although no serious injury is known to have resulted from this cause.

The extent of the danger of gasoline in sewers is indicated by the fact that between 2500 and 3000 garages are estimated to be in use in New York and a large number of cleaning establishments. In 47 garages, within a total of 307 working days, the oil separators which are required to be used yielded 70-1/4 barrels of a mixture of heavy oil, kerosene and gasoline. A test of 3000 gallons of such collected material showed that it contained 40 per cent. of gasoline. In another case 250 barrels of such a mixture were collected from 50 garages between May 2 and July 18, 1913, and 43 barrels were collected from a large taxicab garage between May 2 and July 16. No information could be obtained concerning the amount of waste gasoline from dry cleaning establishments. A very large number of the garages are in rather restricted districts, so that the quantity of this waste there is large. In spite of drastic regulations prohibiting the discharge of this refuse into the sewers, and the existence of companies which buy the wastes to refine them, the explosions are continuing, although with less frequency. The sense of smell also shows that much gasoline still reaches the sewers. It is Mr. Hufeland's opinion that the existing regulations would absolutely prevent such explosions if they were enforced. He was unable to find any field test of the presence of gasoline which was simple enough to be put into the hands of sewer workmen, and he advised restricting the work of sewer exploration in districts where danger from gasoline exits to men who have a thorough knowledge of the subject and will obey and enforce the precautions which experience indicates to be necessary.

Causes of Ignition.—Doubtless explosive mixtures of gas are present in sewers a great many times when no explosions occur. Two conditions are necessary to create an explosion, the presence of an explosive mixture of gases and the ignition of these gases. Until within the last 20 years probably most of the explosions were set off by the use of free flames for lighting purposes by men employed in inspecting or cleaning sewers. Since the advent of electric traction and lighting, the electric spark is more likely to be the cause of ignition than it was in earlier years. In many cases the sparks are above the surface of the street, and there is but a remote possibility of their causing the ignition of gases in sewers, although if they are generated close to manhole or inlet covers there is a possibility of ignition from them. In other cases the sparks are generated in underground conduits, as is thought to have been the case when the explosion took place in New York on September 21, 1914. There are many other opportunities for the ignition of gases in sewers, such as by lighted matches thrown or dropped into manholes or inlets, cinders and sparks from fire engines, locomotives and heating kettles, and possibly from spontaneous combustion by phosphine gas, as suggested by Prof. W. P. Mason in connection with the explosion of one of the Saratoga septic tanks. (*Jour. New England Water Works Assoc.*, 1907, p. 23.)

Prevention of Explosions.—How to prevent explosions in sewers appears to be one of the most important and perplexing problems before sewerage engineers today. The conditions surrounding the causes are such that the solution of the problem bids fair to be expensive and to involve restrictions which will prove more or less onerous to persons using inflammable liquids and which will arouse criticism and unpleasant comments regarding engineers and others having in charge the enforcement of the necessary regulations.

A small percentage of gasoline vapor in air is sufficient to form an explosive mixture. It may be possible in some cases to provide sufficient ventilation in sewers to assure a dissipation and dilution of the vapor great enough to reduce the danger of explosion to a minimum. Whether or not much can be accomplished in this way, it appears wise to secure as good ventilation as possible in the sewers.

It may perhaps be desirable to give more attention to designing sewers so as to provide self-cleaning velocities and thus avoid deposits of organic matter which may give off combustible gases, although this seems to be a remedy of minor importance.

Gasoline is readily volatilized at temperatures above 50° F. It is well known that large quantities of hot water, exhaust steam and sometimes live steam are discharged into sewers from public and private buildings. This is particularly true in northern climates during the winter, when heating systems are being forced, and it is not infrequent in cities to find manhole covers so hot that the naked hand can hardly be kept upon them. Under such conditions volatile liquors like gasoline are quickly converted into vapor. If, on the other hand, the air in the sewer is cool and the temperature of the sewage is normal, the tendency toward volatilization will be much reduced. While this condition will not assure safety, the danger of explosion can be reduced by preventing the discharge of hot water and steam in large quantities into the sewers. This hot water is very objectionable from several other points of view.

Something can be done to reduce the danger of ignition of gases. Greater care can and should be exercised by those entering and working in the sewers to avoid throwing matches into manholes and to use electric lamps in place of open-flame lanterns. Greater care can also be exercised in avoiding an opportunity for the communication of electric sparks to sewers. Whatever may be done in this direction, however, cannot overcome the danger of ignition and for a complete solution of the problem it will be necessary to turn to a restriction of the discharge of inflammable fluids into the sewers, in addition to other preventive measures.

The evidence at hand appears to indicate conclusively that a more serious effort should be made in all cities to prevent the discharge of inflammable materials into sewers, and this appears at the present time to be the most fruitful field of endeavor to prevent sewer explosions. Many cities are now provided with ordinances which, although not drawn expressly to prevent the discharge of gasoline and other inflammable liquids, are sufficiently broad to prevent such discharge if enforced. Some cities have recently adopted new ordinances governing the discharge of inflammable liquids. Such an ordinance is given on page 538 to serve as a guide to those who are drafting similar rules.

It is probable that the quantities of gasoline discharged from private residences and private garages is not generally sufficient to cause explosions under ordinary conditions, although there is a possibility that

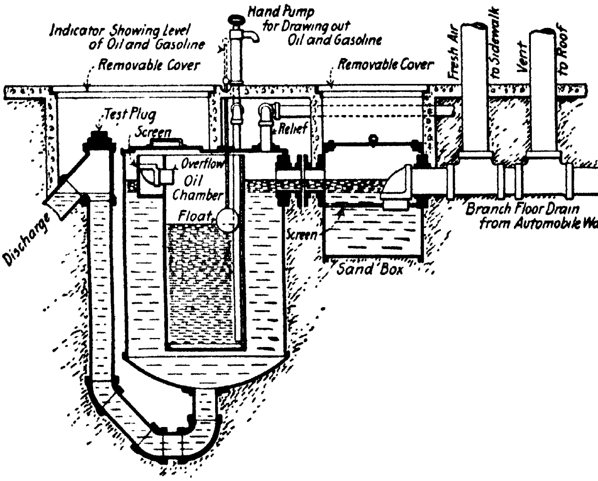

FIG. 179.—Paragon gasoline and oil separator.

explosive mixtures may be caused even by the small amount from such sources.

An important step has been taken in a number of cities in requiring sewer connections serving garages and other buildings in which inflammable fluids are used to be equipped with oil separators, of which several different types have been designed. Their utility is based upon the fact that oil and gasoline are lighter than water and consequently will float upon its surface if given a suitable opportunity, which it is sought to provide by means of these devices.

The Paragon gasoline and oil separator is an apparatus which has been put upon the market by the Ansonia Manufacturing Company of

New York, to meet the regulations just quoted. In it, as indicated in Fig. 179, by taking advantage of the difference in specific gravity, the oil and gasoline are allowed to overflow into an oil chamber while the water passes through the trap and out into the sewer. From time to time, as oil and gasoline accumulate in the chamber, they are drawn off or pumped out.

Where separators are used, the regulations or ordinances of the city should provide for regular and frequent inspection of them and for the removal of the oil contained in them by the owners, contractors, or, preferably, the municipality. If this is not done effectively, the separators will fail to serve the purpose for which they are installed.

Safety Precautions.—The occasional presence of illuminating gas in sewers has been a matter of common knowledge for a great many years. It does not seem that there is at present any tendency toward an increase of this sort of trouble, and so far as the authors know there are no means of preventing its occasional occurrence. It is usually discovered and reported before an explosion occurs. When reported, every effort should be made to immediately ventilate the sewer in which it is found and to locate the leak in the main which is permitting the gas to escape. The trouble arising from gasoline vapor in sewers appears to have increased greatly in the last few years with the larger number of gasoline engines and automobiles in use. Something toward decreasing the danger can be accomplished by means of oil separating traps, thoroughly well ventilated, to prevent the escape of gasoline into sewers.

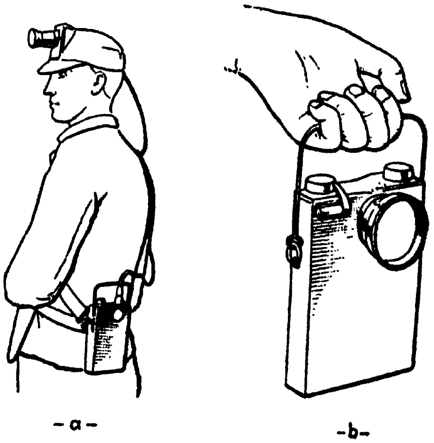

FIG. 180.—Electric head light and electric lantern.

This does not seem to have met with general application, however, and great care should be exercised by those entering sewers to avoid igniting explosive mixtures of gas which may be encountered therein. One of the best means of accomplishing this is to substitute the electric lantern for lamps with open flames for use in inspecting or working in sewers.

An instructive discussion by D. B. Rushmore of safety lamps and a new electric light for miners appeared in *Engineering News*, Aug. 15, 1912. The electric lamp, made by the General Electric Co., is a combination of the hand-lantern and headlight, consisting of a miniature tungsten lamp-unit operated from a light storage battery. The battery has a capacity of 5 amp.-hr., and is of sufficient size to operate a lamp from 12 to 14 hr. When used as a headlight the lamp is fastened to the miner's cap and connected by a flexible cord to the battery, which is flat, 6–1/2 × 4–5/8 × 1–1/8 in., weighing 3 lb. and is carried on a belt as shown by Fig. 180a. When used as a hand lantern, Fig. 180b, the lamp socket is removed from the cap receptacle and inserted in the receptacle on the side of the battery, simply taking the place of the cable-attaching plug.

Ordinances and Regulations Governing Discharge of Inflammable Liquids.—The following ordinance from Washington, D. C., appears to provide as ample protection as is possible by law:

"Sec. 18. No persons shall make or maintain any connection with any public sewer or appurtenance thereof whereby there may be conveyed into the same any hot, suffocating, corrosive, inflammable or explosive liquid, gas, vapor, substance or material of any kind; and no persons shall cause to enter or flow into any public sewer or appurtenance thereof any hot, corrosive, suffocating, inflammable or explosive liquid, gas, vapor, substance or material of any kind; provided, that the provision of this paragraph shall not apply to water from ordinary hot-water boilers of residences."

The special regulations adopted in Washington to carry out this ordinance read as follows:

"1. Every garage or other structure for the housing, sale or repair of automobiles, which is provided with a water supply of either a temporary or permanent character, or in which automobiles are washed, cleaned or repaired, shall be provided with proper means for draining the floors and repair pits, in such a manner that no drainage therefrom shall flow over any street, alley, or paved approach.

"2. Any drain in the floor or repair pits of any garage or other structure for the housing, sale or repair of automobiles, whether required to be provided under paragraph 1 of this section or not, shall have a special sewer connection separate from other waste or soil connections, and shall discharge into an intercepting trap which shall be located outside of the building and connected with the house sewer between the building walls and the public sewer.

"3. This trap shall be so arranged as to intercept all oils, gasoline, or other inflammable fluids, as well as sand, silt and other solids, for the purpose of excluding same from the sewerage system. It shall be water-tight, of substantial masonry construction, so located as to be easily accessible for cleaning and inspection, shall be provided with a standard Sewer Department cast-iron manhole frame and cover, except that in locations within yards and where not subject to traffic a suitable lighter cover may be used, shall be of design approved by the Engineer Commissioner, and shall have a depth of not less than 2 ft. below the grade of the drain pipe, with a net capacity of 6 cu. ft. where the storage capacity does not exceed three (3) automobiles; where the storage capacity exceeds three (3) automobiles 1 cu. ft. in net capacity shall be added for each additional automobile.

"4. Such traps shall have the accumulated oils and other inflammable fluids pumped or otherwise removed therefrom at regular intervals, and shall be so maintained as to insure the exclusion of the same from the sewerage system. They shall also be kept free of sand, silt and other solids, and will be subject to a periodical inspection by the Superintendent of Sewers.

"5. Every existing garage or other structure used for the housing, sale or repair of automobiles shall be provided with a floor drain and garage intercepting trap in accordance with this section, within sixty (60) days after notice from the Commissioners."

A type of trap said to be approved under these regulations is a brick or concrete basin into which the drain from the garage discharges. The outlet pipe is provided with a 90-deg. elbow pointing downward, into the lower end of which is fastened a short length of pipe. The elevation of the outlet pipe is such that the elbow and short pipe attached to it effectually trap the basin, the normal minimum seal being 6 in.

On Jan. 3, 1912, the Municipal Explosives Commission of New York adopted a code of regulations, some of which bear directly upon the admission of inflammable oils to the public sewers, and are here quoted as of interest to those having in charge the operation and maintenance of sewers.

"Sec. 289. It shall be unlawful for any person to connect an oil storage plant with any public drain or sewer, or to permit any liquid product of petroleum to escape into any such drain or sewer within the City of New York.

"Sec. 376. No garage permit authorizing the storage of volatile inflammable oil shall be issued for any premises which are not provided with an oil separator, trap or other similar apparatus attached to the house drain for the purpose of preventing volatile inflammable oils from flowing into the sewer; provided, however, that the Fire Commissioner may, upon the recommendation of the Municipal Explosives Commission, exempt from the requirements of this section a garage draining into a short sewer line.

"Sec. 396. Each oil separator installed in a garage shall be connected to the house drain, and shall be so arranged as to separate all oils from the drainage of the garage.

"Sec. 397. The oil receptacle of an oil separator shall not exceed 50 gal. capacity, and shall be emptied as often as may be necessary to prevent the oil from overflowing; and such oils as are recovered from the separator shall be removed from the garage within 24 hours after being taken from the separator.

"Sec. 435. It shall be unlawful for any person to discharge any volatile inflammable oil into any public drain or sewer.

"Sec. 444. The holder of a permit to maintain and operate a dry cleaning or dry dyeing establishment shall not be required to obtain a permit to conduct the business of sponging."

It is comparatively easy to draft ordinances and regulations which, if strictly enforced, would prevent the discharge into the sewers of most of the inflammable liquids now finding their way into them, and in most cities it is probably possible to secure the passage of them. It is not so easy, however, to enforce such laws, and the chief difficulty with this line of attack on dangerous sewer explosions will come in the enforcement. In the larger cities, probably, much difficulty will be encountered, for many of the owners of garages and industrial establishments will oppose restrictions which may appear to them to be unfair. The repetition of such explosions as have recently occurred in Pittsburg, New York and other cities will do much toward creating a public sentiment which will assist city officials in enforcing regulations.

Other Dangers.—Even though the danger of explosion is avoided, in exceptional cases gases may be present in sufficient quantities and of the proper kind to endanger the men working in the sewer. Illuminating gas, while most common, may usually be detected by its odor. If however, there are some gas works wastes in the sewage which impart odor to the air and yet are not dangerous, the men may gradually come upon a quantity of illuminating gas without noticing the difference in odor and be overcome, with dangerous results. There is also danger from marsh gas formed in decomposing deposits and liberated in large quantities when these deposits are disturbed, as by being shoveled or walked upon. Hydrogen sulphide may also be formed under similar conditions, especially where the sewage contains sulphates, as from very hard water or sea water. An illustration of such conditions is furnished at the gate chamber at the end of the Los Angeles outfall, mentioned in Volume I.

Another illustration is afforded by the death of three experienced sewer workmen at New Bedford, Mass., on April 10, 1914. A section of an intercepting sewer had been closed by a bulkhead in order that the portion below the bulkhead might be put in use while that above was being completed. The men entered the sewer at a manhole 500 ft. above the bulkhead. They adopted none of the precautions advised in this chapter. About 8 hours later, their bodies were found by a searching party under conditions which indicated that they had probably worked their way well down toward the bulkhead, when they discovered the presence of gas. One of them escaped to within 100 ft. of the manhole and then fell over with his face in a little trickle of water on the invert, in which he was practically drowned. The others did not get nearer than 300 ft. to the manhole; their bodies were found against the wall of the sewer, the arm of one through that of another in a way indicating that he was helping the latter along when both collapsed.

The only practicable way in which to avoid danger of being overcome by such gases as may be found in sewers under exceptional circumstances appears to be to provide liberal ventilation before entering and while working in them. Care should also be exercised to provide young and vigorous men for such work, to see that there are sufficient men in the party to provide necessary assistance in case of need, and to require that life belts be used when the men are in particular danger. For emergencies the breathing apparatus used in mine rescue work and for entering burning buildings may prove useful. Such apparatus is described in Miners' Circular 4, U. S. Bureau of Mines. One type is illustrated by Fig. 181. It consists essentially of a cylinder of oxygen, a breathing bag and a regenerator or device for removing the carbon dioxide from the exhaled air. The operator breathes through the mouth from a tube leading from the breathing bag which constitutes the reservoir of air, the oxygen in which is kept at the proper proportion by the supply from the oxygen cylinder. The exhaled air after being regenerated is used over and over.

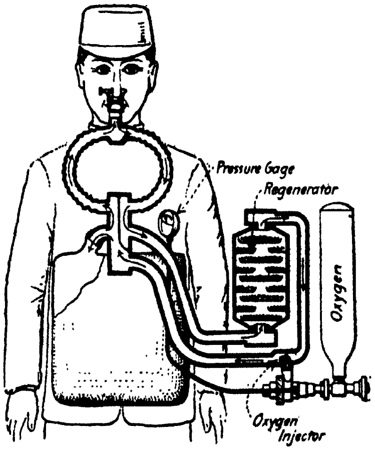

Fig. 181.—Draeger breathing apparatus.

INDEX

INDEX TO TABLES AND ILLUSTRATIONS

INDEX TO TABLES

No.	0	1	2	3	4	5	6	7	8	9
0	......	11	14	21	53	62	72	72	74	86
10	97	103	104	105	108	109	114	115	122	123
20	124	125	127	135	145	148	149	150	155	162
30	163	165	167	169	173	186	198	201	222	224
40	243	243	244	244	249	264	269	274	283	284
50	288	289	293	294	315	318	333	338	358	359
60	362	364	366	375	387	388	415	418	425	427
70	428	432	503	508	508	513	514	515	515	524
80	525	525	...	...	...	...	...	...	...	...

INDEX TO ILLUSTRATIONS

No	0	1	2	3	4	5	6	7	8	9
0	......	7	8	9	10	13	14	19	23	26
10	41	46	47	51	i64	68	70	71	73	77
20	80	80	84	84	90	91	92	92	92	93
30	95	96	99	106	i108	i108	110	111	112	112
40	117	119	120	126	140	140	141	145	146	152
50	152	153	154	156	157	i162	218	219	221	227
60	227	228	229	230	230	231	231	232	232	233
70	233	235	235	236	237	241	241	242	242	245
80	245	246	247	248	248	250	251	253	254	255
90	256	256	i256	i257	257	258	259	260	261	262
100	262	263	272	285	286	287	300	306	306	307
110	314	317	318	324	328	330	357	361	362	i362
120	i362	i363	i363	377	379	379	380	380	380	383
130	i388	i389	390	392	394	397	398	399	402	i402
140	i402	405	408	i408	i408	i409	i409	411	413	i414
150	i414	i415	i415	416	417	419	421	422	422	423
160	i432	i498	500	500	502	502	503	504	504	505
170	505	506	507	i508	i508	i509	512	515	517	536
180	537	541	......	......	......	......	......	......	......	......

The number of the table or illustration is to be found by taking its unit figure in the horizontal line at the top of each table and the tens and hundreds figures in the left-hand column. In the space corresponding to the intersection of the vertical and horizontal lines will be found the page on which the table or illustration appears. For example, Fig. 113 is on page 324. The letter *i* shows that the illustration is on an inserted sheet and faces the page stated.

SUBJECT INDEX

A

Abandoned work, 458
Absorption, brick, 351, 352
  pipe, test, 296, 484
Accidents, contractor's responsibility, 458
  falling trench braces, 263
  frozen dynamite, 138
  gases in sewers, 540
  riveted pipe floated, 320
  rock slides in trenches, 268
  shoring, 214, 234, 271, 280
  trench machines, 83
  unloading holes, 144
  wind blows floated pipe, 328
Acetylene, cause of explosions in sewers, 531
Acid, cleaning concrete with, 391
  hastens settling of washed samples, 11
Adams, A. A.; cleaning sewers, 499
Adamson, Robert; causes of explosions in sewers, 531
Adhesion, in earth, 270
Administration, expenses at Louisville, 169
  organization at Louisville, 23
Advertisement of contracts, 441
Aftercooler, on compressed air plant, 122
Aggregates, 374
  gravel, 372
    specifications, 474
  stone, broken, 474
    inspection, 33
Air, compressed, 121
  advantages in drilling, 109
  cooling and reheating, 122
  drills, 105
  tunneling, 258
Air compressors, 126
  locks on sewer tunnel under pressure, 259
Aldrich, Allen; sewer-cleaning tools, 507
Alkalies, action on concrete, 370
Alluvium, angle of repose, 269
  shoring trenches in, 267
  stay-bracing trenches in, 237
Alterations in contract quantities, 458
Alum and soap for making concrete impervious, 386
Alvord & Burdick; classification of excavation, 56
Ambler, J. N.; sewer cleaning, 501
American Engineering & Construction Co., steel forms, 412
Ammonia powder, 134
Angle of repose, 268
  increased by compression, 278
Anvel, R. G.; cleaning sewers, 501
Arbitration, bars, 478
  cannot be made compulsory, 437
  clauses, 438
  engineer's duty under contract agreements, 435
Arching of backfilling, 153
Arch-timbering of tunnels, 257
Areas, averaging end, 159
Asphalt joints, 339
Asphyxia from fumes of explosives, 137
Atlas powder, 132
Augers, for sampling earth, 7, 14
Austrian method of tunneling, 66
Automobile insurance, 444
  for cleaning catch-basins, 510
Auxiliary valve for drills, 106

B

Backfilling, arching produced by narrowed bottom of trench, 153
  frozen material unsuitable, 311
  inspection, 35
  Iowa specifications, 309
  methods, 309
  no adhesion to bank, 270
  puddling, 309, 311
  rock in, 128
  rolling, 310
  specifications, 471
Bags for mortar for joints, 332
Bailing, 67
  specifications, 471
Baker, Ira O.; angle of repose, 268
Ballast, 475
Balls for cleaning sewers, 506
Baltimore, Md.; condensing water from underdrains, 78
  waterproofing concrete sewers, 389
Barbour, Frank A.; asphalt joints for pipe sewers, 340
  classification of excavation, 56
  pipe joints, 335
Bars, arbitration, 478
  reinforcing, 384, 406, 475, 477, 482
  slicing, for tamping around steel, 382
  to support roof in tunneling, 255
Batavia, N. Y.; foundations in wet trenches, 302
  joints in wet trenches, 332

Batch concrete mixers, 377
Bates, John S.; asphalt joints for pipe sewers, 340
Bates, W. F.; laying subaqueous outfall, 324
Batter boards, on piles along outfall sewers, 30
  transferring line and grade, 26
Batteries, blasting, 144
Bearing strength, vitrified pipe, 297
Beetle, for driving sheeting, 262
Belgian method of tunneling, 65
Bells, Coffin's study of their shape, 335
  specifications, 483
Bench marks, located by preliminary surveys, 3
  position for giving sewer grades, 27
Bench wall forms, 399, 401, 404, 406, 411
Beveling sheeting, 219, 240
Bidders, information for, 441
  bonds, 443
Bids, form of proposal, 442
  where alternative materials may be used, 347
Bill of material for shoring trenches, 224, 225, 226
  full round wood forms, 418
Bits for drilling
  hand drilling, 102
  steam and air drilling
    length, 107
    sharpening, 116, 120
    tempering, 119
Bituminous joints, 339
Blanket clauses, 436
Blanks for records, branches, 305
  force account, 46, 47
  general and overhead charges, 49
  labor on pipe laying, 44, 50
  manholes, 305
  materials and supplies for pipe laying, 45
  sewerage statistics, 517
  tools, equipment and repairs in pipe laying, 48
  total cost of pipe laying, 48
Blasting, care necessary in trench work, 129, 268
  cleaning holes, 142
  cost in trenches, 150
  cut and breaking-in shots, 67
  fumes, 137
  machines, 144
  priming cartridges, 142
  spacing holes, 103
  specifications, 470
  using different explosives in a hole, 135
  wet holes, 138
Blaw Steel Construction Co.; steel forms for concrete, 407
Block sewers, vitrified, 361
  concrete, 362
Block-holing, 113
Blocking pipe, 317
Blocks to lengthen trench braces, 231
Board of Local Improvements, Chicago, rock excavation specifications, 57
Board of Water Supply, New York; construction of concrete invert, 391
  leveling requirements, 3
  requirements for brick, 351
Boilers, steam drilling, 107
Bond, in brickwork, 354
Bonus payments, 451
  Louisville sewerage construction experience, 169, 452
Borings, auger, 7, 14
  core drill, 15
  frequency of holes, 16
  punch, 6
  recording materials on profiles, 14, 21
  wash, 8
Boston, brick laying performance, 356
  explosions in sewers, 532
  grease in sewers, 494
Boston Society of Civil Engineers, summary of sewerage statistics, 517
Bowlders, dobe blasting, 143
  measurement, 55
Boxes for thawing dynamite, 141
Box sheeting, 232
Boynton, C W ; pipe-testing machine, 295
Braces, trench, blocks to lengthen, 231
  extension, 233, 263
  placing, vertical sheeting, 216, 265
  presence affects concrete operations, 420
  quantity of lumber needed, 222, 226
  size, 222, 240, 281, 286
  spacing, 216
  times used, 224
Bracing, on curves, 238
  stay, 236
Branch, E. W.; cleaning sewers, 499
Branches, location, 39, 304
  records, 38, 306
  stoppers, 307
  specifications for placing, 486
Breakage, vitrified pipe, 291, 292
Breathing apparatus, 541
Breed, J. B. F.; engineer's estimates and contract costs, 162
  shoring Louisville sewers, 227
  specifications, 466
Breneman, A. A : explosions in sewers, 529
Brewer, Bertram; flushing sewers, 497
Brick, advantages and disadvantages, 347, 349, 367
  broken, in manholes, 352
  cost of brick sewers, 360

Brick, handling, 352
  inspection, 33
  laying, 354
    use of profile, 397
    specifications, 478
  plastering, 479
  quality, 350
  rate of progress, 360
  size, 350
  specifications, 478
  tests, 351, 352
  vitrified, 369
Brockton, Mass.; flushing sewers, 497
Bronx Valley sewer, using materials from trench, 371
Brooklyn, Borough of; bituminous joints for pipe sewers, 341
  cleaning catch-basins, 514
  cleaning sewers, 503
  tests of vitrified pipe, 298
Brown, N. A.; wash borings, 12
Brunton bit, 118
Buckets, bottom-dump, 380
  concrete, 379
  cost of excavation, 161
  excavating, 98, 320, 322, 323
Buckeye traction ditcher, 95
  cost of excavation, Denver, 167
  performance at Denver, 199
Buffalo, N. Y.; explosions in sewers, 530
Buggy, concrete, 379
  pipe, 300
Buildings, measurements where settlement may occur, 81
  records taken on preliminary surveys, 4, 22
  records taken during construction, 35
Bulkhead at end of construction section, 401
Burns & McDonnell; classification of excavation, 57
Butterfly valve for drills, 106

C

Cableway, use on sewer trenches, 93
Caisson on sewer tunnel under air, 259
Calcium carbide, source of explosive gases, 531
Canals, cost, 160
Caps for explosives, 142
  storage, 149
  for sheeting planks, 263
Car for concrete, 380, 381
Carbonite, 132
Carbons for core drills, 15, 16
Car-load, feet of pipe in, 292
Carpenter, George A.; cleaning catch-basins, 510
Carson-Trainor hoister and conveyor, 93
Carson trench machine, 83, 232
Carter, Frank H.: thickness of sheeting, rangers and braces, 287
Carts for catch-basin refuse, 514
  automobile, 510
Cartridges, dynamite, 134
  priming, 142
Casting earth in excavation, 60
Castings, iron, 478
Catch-basins, cleaning, 509, 525
  freezing, 511
  location, 526
  oiling to kill mosquitoes, 516
  specifications, 487
Cattell, W. A.; classification of excavation, 56
Catskill Aqueduct; brick requirements, 351
  construction of invert, 391
  leveling requirements, 3
  time forms were in place, 431
Cellars, effect of underdrains, 75
  preliminary records of depths, 4, 22
Cement, inspection, 31
  joints in pipe sewers, 331
  non-decomposable, 370
  specifications, 473
  testing with sand to be used, 32, 354
  volume, 376
  wash on brick sewers, 355
  weight, 376
Centers, block, 398
  brickwork, construction, 397
    specifications, 479
    withdrawing, 354, 398
  concrete, cleaning, 428
    curves and junctions, 424
    handling, 432
    length, 409
    lubrication, 429
    lumber for, 424
    metal-covered wooden, 403
    peeling, 407, 429
    prevention of swelling, 418, 424
    specifications, 48
    steel, 404, 407
      cost, 428
    time in place, 430
    wooden, 398, 404
      cost, 425
Centrifugal pumps, 68
Chain rope, 300, 353
Changes in soil conditions, 270
  in contracts, 435, 436, 460
Charges for engineering services, 53
Chicago, Lawrence Ave tunnel shield and lining, 257
Childs, Stephen; underdrainage at Newton, 76
Chocking blocks, in tunneling, 255
Churn drilling, 101
Chutes, concrete, 381

- Cincinnati, Ohio; sewer brick requirements 351
  - topographic map, 20
  - underground survey, 2
- Clam-shell buckets, 98
- Clamp, friction, for drawing boring rod, 7
  - pulling steel sheet piles, 247, 248
  - sheeting, 262
- Classification of excavated materials, 55
- Clay, and linseed oil joint compound, 342
  - angle of repose, 269
  - for making impervious concrete, 386
  - joints in pipe sewers, 330
  - shoring trenches in, 267
  - tunneling through, 251
- Cleaning, catch-basins, 509
  - centers and forms, 428
  - concrete before resuming laying, 391, 429
  - drill holes, 105, 108, 113, 142
  - pipe after laying, 334
  - sewers, 501
  - underdrains, 78
- Cleats on trench braces, 216
- Cleveland, Ohio; submerged steel outfall, 327
- Cloth wrapping on pipe joints, 332
- Cochran, Jerome; lumber for wood forms, 424
  - lubricating forms, 430
- Coffin, Freeman C.; tests of pipe joints, 334
- Cohesion, effect on earth pressures, 269
- Cold weather, concrete work in, 391
- Collier, James, machine and hand excavation, 167
  - rate of progress on construction, 199
- Colors, for maps, 21
  - red for main results in computation, 41
  - used in contrasting weekly and monthly records, 51
- Columbus, Ohio; barges used in sewer cleaning, 502
  - deposits in sewers, 495
- Commission on Additional Water Supply, New York; wash borings, 11
- Compensation, workmen's, 443
- Competitive bids on alternative materials, 347
- Compressed air, 121
  - advantages in drilling, 109
  - cooling and reheating, 122
  - drills, 105
  - requirements for 1 or more drills, 121
  - transmission, 122
  - tunneling, 258
- Compressors, air, 126
- Computation sheets, preservation, 40
- Concord, Mass.; heavy earth pressures in storage well, 279
  - flushing sewers, 498
- Concord, Mass.; roots in sewers, 500
- Concrete, advantages and disadvantages, 347, 349, 367
  - block sewers, 362
  - cleaning before resuming laying, 391, 429, 481
  - cost, factors affecting, 414
    - Louisville, 186
  - cracks caused by swelling centers, 418
  - cradles for pipe, 302, 308, 317
  - disintegration by chemical action, 369
  - extra amount to avoid using outside forms, 157
  - maximum density desirable, 373
  - mixing, hand, 374
    - in restricted space, 378
    - machine, 377
    - relative economy of hand and machine, 376
    - specifications, 480
  - placing, 382, 481
    - affected by trench bracing, 420
    - in freezing weather, 391
    - Louisville, 393
  - proportions of sand, stone and cement, 372
  - quantity in Louisville sewers, 186
  - rate of progress in Louisville sewers, 201
  - rubble, 481
  - spading and slicing, 382, 481
  - specifications, 480
  - surfaces, keeping stone from, 383, 481
    - granolithic, 482
  - transporting, 379
  - wet mixtures needed, 382
  - work joints, 390, 414
- Condensing water from underdrains, 78
- Conduits, record of location in streets, 3
- Conglomerates, cost of excavation, 161
- Contingencies, providing for, in contracts, 436
- Continuous concrete mixers, 378
- Contours, intervals for preliminary surveys, 4, 20
  - on Cincinnati maps, 20
- Contractors, address given in contract, 461
  - examination of conditions before submitting bids, 58
  - favoring local, 165
  - inspection does not relieve contractors of responsibility, 457, 461
  - insurance, 458
  - must afford facilities to others on same undertaking, 457
  - powder, 131
  - relations with engineers, 37
- Contracts, advertisement, 441
  - ambiguity and illegality, 432
  - blanket clauses, 436

- Contracts, changes in, 435, 436, 460
  - compared with force account work, 433
  - contingencies to be provided for, 436
  - cost plus fixed sum, 449
    - with guaranteed limit, 450
  - essentials, 434
  - general form of engineering, 441
    - authors' form, 455
  - lump sum, 448
  - must agree with advertisement, information for bidders and proposal, 443
  - New York precautions in drawing, 433
  - oral statements modifying, 436
  - percentage, 448
    - on labor and materials, 449
  - preparation, 22
  - printing, 455, 463
  - restricted to local bidders, 165
  - should be clearly expressed, 434
  - surety's interest in changes, 436
  - unit price, 446
- Coping stones, 480
- Copper spoon for unloading blast holes, 144
- Core drilling, 15, 105
- Cost-keeping methods, 43
- Cost plus fixed sum contracts, 449
- Costs, administration, 53
  - backfilling, tamping, 311
  - Buckeye traction ditcher, 97
  - core drilling, 16
  - Denver sewers, machine and hand excavation, 167
  - diaphragm pumps, 68
  - ditching, 160
  - dredging, 160
  - dynamite, 149
  - electric fuse, 150
  - engineering and supervision, 52
  - explosives in rock trenches, 150
  - forms and centers, 396
    - full-round wood, 417
      - erecting, striking and moving, 415
    - handling, 415, 432
    - steel, 408, 428
    - wood, 425
  - hand drilling, 102
  - joints, asphalt, 341
    - sulphur-sand, 338
  - Louisville sewerage system, 162
    - concrete and steel, 186
    - contract work, 169
    - earth and rock excavation, 173
    - engineering and administration, 53, 169
  - manholes, 365
  - operation and maintenance of sewerage systems, 522
  - pipe, jointing, 313
    - laying, 312
- Costs, subaqueous pipe laying, 323
  - rock excavation, 104
  - sewers, brick, 360
    - cleaning, 49[illegible], 501
    - concrete in, 394, 414
    - influence of different factors, 195
    - per foot of diameter of 1 lin. ft. of sewer, 394
  - soundings in earth and hardpan, 7
  - steam shovel excavation, 160
    - in trench, 94
  - topographic surveying and mapping, 21
  - trenching by hand and machine, 82, 167
  - tunneling, 63
  - vitrified segments, 361
  - wash borings, 12, 13, 14
    - rig, 10
  - work of Carson trench machine, 89
- Couplings for sewer rods, 507
- Cracks in concrete, 390, 391
  - due to swelling centers, 418
- Cradles, brick sewers, 355
  - pipe sewers, 303, 308, 317
  - specifications, 485
- Cranes, gantry, for pipe laying, 318
  - traveling, on trench excavation, 98, 320
- Crown-bar timbering, 256
- Curbing, specifications, 488
- Curtis puller for steel sheet piling, 247
- Curves, bracing trenches on, 238
  - Carson excavating machine on, 89

D

- Damages due to alterations in contract quantities, 458
  - liquidated, 451
    - experience at Louisville, 169, 452
  - suits at Louisville, 162
- Dana, Richard T.; explosives, 130, 135
- Darlington, Dr. Thomas.; treatment of asphyxiation by fumes, 137
- Day labor, compared with contract work, 433
  - cost keeping, 46, 47
  - experience at Louisville, 162, 165
- Deaths in sewers, 540
- Denver, Colo.: cost of machine and hand excavation, 167
  - labor on brick sewers, 357
  - rate of progress on construction, 199
- Deposits in sewers, 493
  - removal, 500
- Derrick for trench excavation, 98
  - handling vitrified pipe, 300
  - scow, 324
  - sulky, for pipe laying, 317
- Detonation, nature of, 130
- Detroit, laying large concrete pipe, 316
- Diamond drills, 15

Diaphragm pumps, 67
Differential valve for drill, 106
Discounts, pipe list prices, 291
Disintegration of concrete, 369
Distance of magazines from buildings and railways, 148
Ditches, Buckeye traction ditchers, 95
  cost, 160
Dobe blasting, 143
Dolly used in sharpening bits, 124
Dopes, in explosives, 131
Dorr, E. S ; grease in sewers, 494
  use of scrapers in sewer cleaning, 506
Drag scrapers for trench work, 98
  cost of excavation, 161
Drainage, 69, 468
  specifications, 471
  underdrains, 75
  with driven wells, 69
Drawings, checking old, 5
  contract, 22, 42, 453
  mapping, 19
  record, 41
Dredging, cost, 160
Dressing lumber, 240, 425
Drifts, definition, 65
  use, 66, 250, 256
Drill steel, hand drilling, 102
  steam drilling, length, 107, 116
    sharpening, 116, 120
    tempering, 119
Drilling, core, 15
  hand, 101
    churn, 101
  jet, 8
  limitations of different methods, 114
  scow, 323
  spacing holes, 103
  steam and compressed air, 105, 115
    boiler capacity, 108
    compressed air needed, 121
    piping for, 107
Drills, electric-air, 110
  hammer, 111
  percussion, sizes for sewer work, 109
    types, 106
    wheel mounting, 110
Drip stones, specifications, 488
Driving caps for sheeting planks, 263
Dropping rock in backfilling, 471
Dualin, 132
Dunn, Col. B. W.; shipment and storage of explosives, 147
du Pont de Nemours Powder Co., E. I.; blasting machines, 144
  priming cartridges, 142
  thawing dynamite, 139
Dynamite, amount for trench excavation, 104, 105
  cartridges, 134
Dynamite, composition, 131, 135
  cost, 149
  disposing of unused, 144
  freezing, 138
  priming, 142
  rating strength, 134

E

Earl, George G.; contract for labor and materials on percentage basis, 449
Earth, adhesion, 270
  angle of repose, 268
  changes in character, 270
  cohesion, 269
  determination of character by sounding, drilling and boring, 6
  excavation, 54
    cost at Louisville, 173
  pressures, 271
    Carter's diagram, 287
    hydrostatic conditions approximated, 275
    Meem's theory, 277
    Rankine's formula, 271
  selection for backfilling, 311
  shrinkage, 310
  tunneling in, 65
Earthwork, measurement, 158, 469
  shrinkage, 310
Elberfeld, asphalt joints in pipe sewers, 339
  tests of pipe sewers, 346
Electric-air drill, 110
Electric current, voltage for tunnels, 64
Emergency work, 456
Emerson steam vacuum pump, 72
End areas, averaging, for quantities, 159
Engineering, cost, 52
    Louisville, 169
  department for construction, 22
  diagram of Louisville organization, 23
  work during construction, 25
Engineers, arbitrators, 435
  charges for services, 53
  decision regarding workmanship and materials, 456, 459
  may require discharge of men, 457
  relations with contractors, 37, 456
English method of tunneling, 66
Equipment, cost keeping, 48
Estimates, concrete in sewer, 394
  final, 460
  for bidders, 446
  frequency, 39
  Fuller's rule for concrete, 39
  monthly, 460
Examination, local conditions by contractors before bidding, 58
  sewers, 492

- Excavation, below grade prevented by inspector, 35
  - below pipe in rock trench, 56, 128, 464
  - bottom of trench, Iowa specifications, 308
    - authors' specifications, 464
  - cableway, 91
  - Carson-Trainor hoister and conveyor, 93
  - Carson trench machine, 83, 232
  - classification of materials, 55
  - cost, different methods, 160
    - Louisville, 173
  - danger due to previous, 238
  - derricks and cranes, 98
  - drag scrapers, 98
  - endless chain machines, 93
  - excavating buckets, 98
  - frozen material, 59
  - general discussion of subject, 54
  - giving grades, 29, 464
  - hand, 58
  - hydraulic, 325
  - inspection, 34
  - lines of, 152, 454, 464, 467
  - measurement, 469
  - near bottom of trench with machinery, 99
  - Potter hoister and conveyor, 90
  - quantity, 151
  - quicksand, 81
  - rate of progress, Denver, 199
    - Louisville, 201
  - special structures, 467
  - specifications, 467
  - steam shovel, 93
- Exploders, 142
  - storage, 149
- Explosions in sewers, 492
  - Boston, 532
  - Buffalo, 530
  - causes of ignition, 534
  - Hartford, 531
  - Manhattan, 529, 531
  - New Haven, 530
  - ordinances and regulations to prevent, 538
  - Philadelphia, 530
  - Pittsburg, 528
  - prevention, 535
  - sources of inflammable gases, 527, 531, 533
- Explosives, ammonia powder, 134
  - cartridges, 134
  - cause of disruptive effect, 130
  - composition of numerous explosives, 132
  - contractors' and Judson powder, 131, 133
  - dopes, 131
- Explosives, dynamite, 131
  - gelatin, 134
  - gunpowder (black powder), 130
  - magazines, 147
  - nitroglycerin, 131
  - rapidity of action, 135
  - selection for economy, 136
  - shipment, 147
  - strength rating, 134
  - two grades in a hole, 135
  - wet-hole explosives, 138
- Extension braces, 263
- Extra payments, contract clauses, 459
  - Louisville sewerage extras, 169

F

- Farnum, Loring N.; subaqueous pipe laying, 322
- Felton, C R ; flushing sewers, 497
- Fences on trenches, 456, 468
- Ferro Concrete Co.; wooden forms for large sewer, 399
- Filtite jointing compound, 345
- Fitch, Charles F ; steel forms, 410
- Flinn, Alfred D ; time forms are in place, 431
- Floating pipe, 326
- Flushing, methods, 496
  - necessity, 493
- Flush-tanks, inspection, 491
- Force account, compared with contract work, 433
  - cost keeping, 46, 47
  - experience at Louisville, 162, 165
- Forcite, 133
- Ford, F. L.; sewer cleaning, 502
- Form of contract, 455
  - of proposal, 442
- Forms (construction), brickwork, 397
  - cleaning, 428
  - cost of handling small, 415
  - curves and junctions, 424
  - full round, 415
  - good workmanship needed, 348
  - handling, 432
  - length, 409
  - lubricating, 429
  - lumber for, 424
  - manholes, 420
  - metal-covered wooden, 403
  - outside, omitted by use of extra concrete, 151
  - peeling, 407, 429
  - specifications, 479, 481
  - steel, 404, 407
    - cost, 428
  - time in place, 430
  - wooden for concrete, 398, 404, 415
    - cost, 425
- Forms (records), branches, 305

Forms (records), force account, daily, 46, 47
  general and overhead charges, 49
  labor on pipe laying, 44, 50
  manholes, 305
  materials and supplies for pipe laying, 45
  sewerage statistics, 517
  tools, equipment and repairs in pipe laying, 48
  total cost of pipe laying, 48
Fort, E. J.; bituminous joints for pipe sewers, 341
  cleaning catch-basins, 514
    sewers, 503
Foundations, in wet trenches, 302
  specifications, 473
  value at Hoboken, 304
Freezing, catch-basins, 511
  condensation in compressed air plants, 122
  dynamite, 138
  guarding concrete against, 591
Friction in compressed air pipes, 124, 125
Frozen earth, excavation, 59
  backfilling, 311
Fuertes, James H ; foundations of Hoboken sewers, 304
Fuller, George W.; classification of excavation, 56
Fuller, Wm. B.; approximate rule for concrete mixtures, 39
  test for concrete of maximum density, 373
Fumes from blasting, effect of, 137
Fungus growths in sewers, 495, 499
Fuse, priming with safety, 142
Fuse, connecting, 146
  electric, 142

G

Gaging stations, should be established early, 5
Gantry crane for pipe laying, 318
Garage traps, 539
Gases in sewers, 527
Gaskets, 318, 331, 335
Gasoline, extent of danger from 1 gal., 532
  nature of explosions, 533
  separator, 536
  source of dangerous gases, 527, 528
Gault, Matthew; cleaning catch-basins, 514
  sharpening bits by machines, 120
Gelatin dynamite, 134
Gelignite, 133
Geological Survey maps, 2
German method of tunneling, 66
Giant powder, 132
Gillette, H. P.; composition of explosives, 132
Gillette, H. P.; labor on brick masonry, 357
  rock excavation, 103, 104
G-K compound, 342
Gneiss, cost of excavating, 161
Go-devil for cleaning pipe, 334
Grades of sewers, checking records, 4
  grade pole, 26
  notebook used in staking out, 41
  transferring line and grade to sewer, 26, 31
Grading material around underdrains, 77
  concrete aggregates, 373
Grady puller for steel sheet piling, 248
Granite, cost of excavation, 161
  drilling holes in, 103
Granolithic finish, 482
Gravel, angle of repose, 269
  inspection, 33
  screening and recombining, 373
  shoring trenches in, 267
  specifications, 474
  using, from trench, 371
  voids, 372
  washing, 371
Gravity concrete mixers, 378, 381
Grease for lubricating forms, 430
  deposits in sewers, 494
  traps, 494
Great Falls, Mont.; disintegration of concrete pipe by alkaline water, 370
Griffin, J. Alden; jointing cement pipe, 333
Griggs, Julian; barges used in cleaning sewers, 502
  deposits in Columbus sewers, 495
Grooves for joints in concrete, 391
Ground, settlement, 79
  water, effect on cost of excavation, 161
    leakage into sewers, gaging, 5
    permissible amount, 36
    records of elevation, 17, 40
    removal from trenches, 67
    stimulated fungus growth, 499
Guaranty by contractor, 460
Guard rails, 220
Guarding trenches, 456
Gunning drill holes, 108
Gunpowder, 130
Gutters, specifications, 488

H

Half-moon for cleaning pipe, 334
Hamlin, Homer; disintegration of Los Angeles outfall, 369
Hammer, bracing, 262
  drills, 111
  hand drilling, 101
  steam, 246, 248, 249
Hammond, G. T.; tests of vitrified pipe, 298
Hand excavation, 58

Hand excavation, cost, 161
  drilling, 101
  mixing, concrete, 374
Handling, materials, brick, 352
  earth, 83
  forms, 432
  mortar, 353
  pipe, 299
  rock, 127
Hanreddy, James; steel forms, 414
Hardness of rock as basis of classification, 57
Hardpan, shoring trenches in, 267
Hartford, Conn.; cleaning sewers, 502
Haul, effect of length on cost of cleaning basins, 512
Havana, Cuba, wheeled trench drills, 110
Hazen, Allen; classification of excavation, 56
Heading, definition, 65
Healey sewer cleaning machine, 505
Heating concrete materials in cold weather, 392
Hempstead, Eng.; lining worn inverts, 516
Hendrick, Calvin W.; waterproofing Baltimore sewers, 389
Hercules powder, 133
Henneking, Carl; asphalt joints in pipe sewers, 339
Hering & Fuller; classification of excavation, 56
Hering & Gregory; classification of excavation, 56
High-center bit, 118
Himes, Albert J.; breaking contracts, 437
Hoboken, N. J.; foundations for sewers, 304
Holes, cleaning drill holes, 105, 108, 113
    with steam, 142
  drill, 103, 105
  explosives for wet, 138, 143
  loading with explosives, 141
  unloading, 144
Holmes, A. L.; subaqueous pipe-laying, 326
Honolulu, H. I.; laying subaqueous outfall, 322
Hook, lifting, 300
  rope, 300, 353
Hoopes, Charles; foundations in wet trenches, 302
  pipe joints in wet trenches, 332
Hopedale, Mass.: performance of drills in quartzite, 115
  lines of excavation, 152
Horizontal sheeting for trenches, 232
Horner, W. W.: soundings in earth, 7
Horse-head, in tunneling, 254
Horsley powder, 133
Hose, by-passing inverts under repair, 516
  for diaphragm pumps, 68
  life differs with steam and air, 109
Hough, Capt. D. L.; mutuality of contracts, 435
Howe, Malverd A.; tests of pipe joints, 334
Hubbard, W. D.; cleaning sewers, 498
Hufeland, O.; explosions in sewers, 532
Hunter, W. D.; cleaning sewers, 498
Hydrants, access during excavation, 468
  records of location, 3
Hydrated lime for making concrete impervious, 386
Hydraulic sluicing, cost, 160
Hydrogen sulphide, influence of water containing sulphates, 370
  presence dangerous to concrete, 369
Hydrostatic pressures on sheeting, 275

I

Illuminating gas in sewers, 527, 532
Industrial wastes, regulations regarding discharge, 496
Information for bidders, 441
  judicial opinion regarding its character, 446
Inlets, 487
Inspection, brick, 33
  cement, 31
  construction, 25, 464
  cost, 52
  cost-keeping, 47
  does not relieve contractor of responsibility, 457, 461
  duties of inspector, 30
  excavation, 34
  final, 36
  maintenance, 491
    precautions for safety, 537
  pipe, cast-iron, 31
    vitrified pipe, 293
    sewers, 345
  sand, 32
  steel for reinforcing, 33
  stone and gravel, 33
Institution of Civil Engineers, president appoints arbitrator of disputed contracts, 440
Insurance, 443, 458
Intoxicants on work, 457
Inverted siphons, inspection, 517
Inverts, early construction, 383, 399, 401, 403, 406
  lining worn, 516
  specifications, 479, 480
  wear, 368
Iowa pipe-laying requirements, 307
Iron castings, specifications, 478
Italian method of tunneling, 66

J

Jackhammer drill, 111

- Jersey City, N. J.; arbitration clause in contract for waterworks, 438
  - laying steel pipe, 319
- Jet, water, cleaning dredged trench, 324
  - drilling rigs, 8
  - driving sheeting, 238
  - loosening material for suction dredge, 325
    - sheeting, 35
  - lowering submerged pipe, 321
- Joint Outlet Sewer, N. J.; tar-cement joints, 341
- Jointite jointing compound, 345
- Joints, asphalt, 339
  - bituminous, 341
  - brickwork, 354, 397
  - cement, 75, 331
    - specification, 485
  - clay, 330
  - filtite, 345
  - flexible, 321, 323, 326
  - G-K compound, 342
    - specification, 485
  - jointite, 345
  - lead, 318, 486
  - leadite, 331
  - marbleoid, 345
  - overfilled, 334, 336
  - plain mortar, 485
  - Stanford, 330
  - subaqueous, 325, 328
  - sulphur-sand, 336
  - tar, 339
  - tar-cement, 342
  - work, 390
- Jones & Laughlin steel sheet piling, 242, 244
- Judson powder, 131, 133
- Jute, burnt to heat pipe, 337
  - gaskets, 318, 331, 335

K

- Kansas City, Mo.; steel pipe laying, 320
  - tests of sewer pipe, 298
- Kellogg, H. J.; explosions in sewers, 530
- Kensico Aqueduct, 17-ft section built in single operation, 420
- Kerosene for lubricating forms, 430
- Kettles for thawing dynamite, 139
- Kieselguhr, 131
- Kimberly, A. Elliott; G-K compound joints, 342, 343, 344

L

- Labor, assigning tasks in hand excavation, 58
  - Carson trench machine, 88, 89
  - cleaning catch-basins, 510
  - cleaning sewers, 501, 505
  - contract requirements, 457
  - cost keeping, 44, 50
  - favoring local, 458
  - flushing sewers, 497
  - G-K compound joints, 344
  - hand drilling, 101, 102
  - inspecting sewers, 493
  - laying sewer brick, 356, 357, 360
    - vitrified pipe, 301, 313
  - management highly important on excavation, 54
  - mixing concrete, 377
  - preliminary estimates of cost, 18
  - pulling steel forms, 409
  - shoveling material from trenches, 60
  - soundings with punch rods, 7
  - steam drilling, 108
  - tamping backfilling, 309
  - wash boring, 10, 13
- Lackawanna steel sheet piling, 241, 243
- Lawns, protected before excavated material is placed on them, 468
- Laying brick, 354, 397
  - concrete in freezing weather, 391
  - pipe, cast iron, 317
    - large concrete, 316
    - specifications, 484
    - steel, 319
    - subaqueous, 320
    - vitrified, 291, 307
- Lead wool, 318
- Leadite, 331
- Leakage of ground-water, gaging, 5
  - inspection, 37, 348
  - permissible amount, 36
  - through tar-cement joints, 342, 345
- Leaves in catch-basins, 511
- Ledge, classification, 56
  - excavation, 101
  - hammer drills for shallow holes, 113
  - measurements and records, 21, 38, 158
- Lehman, Albert C.; time forms are left in place, 431
- Length of sewers, measurement, 158
- Leptomitus, fungus in sewers, 499
- Lettering drawings for photographic reduction, 454
- Leveling, cost, 21
  - preliminary surveys, 3
  - quantity surveys, 158
- Lever and plank clamp, 262
- Leyner drill sharpener, 120
- Liability insurance, 44
- Libby, Dana; cleaning sewers, 498
  - obstructions in sewers, 495
- Life belt, for men inspecting sewers, 493
- Lighting, interior of sewers for examination, 5, 537
  - trenches, 456
  - tunneling operations, 64

- Lime, hydrated, for making concrete impervious, 386
- Limestone, drilling holes in, 103
- Line and grade, given by engineer to contractor, 464
  - transferring to sewer, 26
- Lines of excavation, 152, 454
- Lining tunnels, 258, 412
  - worn inverts, 517
- Liquidated damages, 451
  - experience on Louisville sewerage work, 169, 452
- Loading cars with vitrified pipe, 292
  - drill holes, 141
  - wagons with vitrified pipe, 299
- Loam, angle of repose, 269
- Local contractors, favoring, 165
  - workmen, favoring, 458
- Locks, air, on tunnel under pressure, 259
- Locomotive, cranes, 98, 320
  - electric, for tunneling, 64
- London, arbitration clause in contract, 440
  - cast-iron lining of pneumatic tunnel, 261
- Los Angeles, Cal.; cement pipe joints, 333
  - disintegration of mortar joints of outfall, 369
- Louisville, Ky ; cleaning forms, 429
  - concrete mixing plant, 380
  - cost of borings on preliminary investigations, 14
    - of concrete, 395
      - and steel in sewers, 186
    - of earth and rock excavation, 173
    - of sewers built by contract, 169
  - cross-sections of trenches, 227, 228, 229, 230, 231, 232, 233, 235, 237
  - day labor construction costs, 165
  - distribution of expense of sewerage system, 53
  - full-round wood forms, 415
  - judicial decision regarding character of "information for bidders," 446
  - laying concrete in cold weather, 392
  - liquidated damages and bonus clauses, 164, 452
  - local contractors' bids, 165
  - metal-covered wooden forms, 404
  - organization of staff, 23
  - quantity of excavation in trenches, average, 107
  - rate of progress in placing concrete, 195, 201, 393
  - specifications, 466
  - steel forms, 409, 410, 412
  - steam shovel on construction, 93
  - sulphur-sand joints, 338
  - timbering of tunnel, 255, 256
  - time forms were in place, 431
  - waterproofing experiments, 386
  - wooden forms, 399, 401
- Low center bit, 118
- Lubrication of forms, 429
- Lumber, bill of material for trench shoring, 224, 225, 226
  - for wood forms, 424
  - kinds used for shoring, 239
  - losses, 223
- Lump sum contracts, 448
- Lynn; grease in sewers, 494

M

- Machines for cleaning sewers, 502
  - for digging trenches, 99
    - Buckeye traction ditcher, 96, 97, 199
      - cost of work at Denver, 167
    - cableway, 91
    - Carson, 83
    - Carson-Trainor hoister and conveyor, 93
    - drag scrapers, 98
    - endless chain machines, 95
    - excavating buckets, 98
    - Potter, 90, 91
  - for mixing concrete, 377
  - for tamping backfilling, 311
  - for testing pipe, Boynton, 295
    - Brooklyn, N. Y., 298
    - Iowa, 296
    - Talbot, 295
- Madras, India; disintegration of concrete sewers, 370
- Magazines for explosives, 147
- Maintenance, cleaning and care of catch-basins, 509
  - cost of operation and maintenance of sewerage systems, 522
  - deposits in sewers, 493
  - flushing sewers, 496
  - importance, 491
  - inspection, 492
  - records, 517
  - regulators and inverted siphons, 517
  - removing heavy deposits from sewers, 500
    - roots from sewers, 499
  - repairs, 516
- Malden, Mass.; cleaning sewers, 498
- Manchester, Eng.; tests of pipe sewers, 345
- Manholes, broken brick in, 352
  - castings, 488
  - concrete, forms, 420
  - construction, 365
  - excavation for, 467
  - Hopedale, lines of excavation, 152
  - moving covers, 516
  - quantities, 366
  - recording position, 305
  - reference marks for locating, 25
  - specifications, 487

Manure pits for dynamite, 141
Maps, for preliminary investigations, 2
  street, 18
Marbleoid jointing compound, 345
Marsh gas in sewers, 527
Marshall, Gen. W. L.; waterproofing concrete, 386
Marston, Prof. Anson; narrowed bottom of trench, 153
  pipe testing machines, 296
Masonry specifications, brick, 478
  stone, 479
Materials, bill of, shoring trenches, 224, 225, 226
  bill of, full round wood forms, 418
  choice for large sewers, 367
  cost keeping, 45
  from trench, use of, 371
    depositing so as to leave passages, 468
  list for preliminary estimates, 18
Maul for driving sheeting, 262
McCracken & Co., C. T., metal-covered wooden forms, 404
McGovern, Patrick; subaqueous pipe laying, 325
McKiernan-Terry Drill Co.; core drilling, 15
  sheeting hammer, 248
Measurements, brickwork, 351
  concrete materials, 376
  excavation, 158, 464, 467, 469,
  final, 38
  length of sewers, 158
  monthly, 39, 52
  preliminary, 38
  rock, 55
Meem, J. C.; theory of earth pressures, 277
  timbering large tunnels, 256
Melrose, Mass.; cleaning sewers, 498
Membrane method of waterproofing, 389
Metal-covered wooden centers, 403
Metcalf & Eddy; classification of excavation, 58
  contractor's bond, 462
  contract form, 455
  general specifications, 463
Metcalf, Leonard; earth pressures, Concord, 279
Methane in sewers, 527, 533
Metropolitan Sewerage Commission, New York; grease in sewers, 494
Metropolitan Sewerage System, Boston; oiling forms, 430
  rate of brick laying, 356
  southern outfall construction, 326
Milwaukee, Wis.; subaqueous pipe laying, 322
Mirrors for examining sewer interiors, 5
Mixing concrete, hand, 374
  machine, 377
Mixing concrete, relative cost of hand and machine mixing, 376
Modulus of rupture, pipe, 298
Monmouth, Ill.; asphalt joints on pipe sewers, 340
Moran, H. P.; earth pressures, 280
Morse, Howard S.; timbering a Louisville tunnel, 256
Mortar, composition for best results, 32, 343
  joints in pipe sewers, 331
  masonry, 353
  materials per cubic yard, 359
  on inner surface of concrete sewers, 384
  specifications, 475
Mosquitoes, oil catch-basins to kill, 516
Motor trucks for cleaning catch-basins, 510
Mudcaps, 143

N

Newark, N. J.; cost of forms for aqueduct, 426
New Bedford, Mass.; deaths in sewer, 540
  failure of cofferdam, 81
  subaqueous pipe laying, 325
New Haven, Conn.; explosions in sewers, 530
New Orleans; percentage contract for labor and materials, 449
New Rochelle, N. Y.; submerged outfall, 323
Newton, Mass.; obstructions in sewers and underdrains, 495
  cleaning sewers, 498, 506
  removing roots, 499
  sulphur and sand joints, 337
  tunnel in sand, 252
  underdrains, 76
New York, N. Y.; cleaning Manhattan sewers, 508
  explosions in sewers, 529, 531
  general form of contract, 433
  grease in Manhattan sewers, 494
  regulations regarding explosive liquids, 539
Night work, 456
Nitroglycerin, 131
  use in wet holes, 138
Nobel and Abel; temperatures of explosions of gunpowder, 130
North Attleboro, Mass.; asphalt joints in pipe sewers, 340
Norton, Geo. H.; explosions in sewers, 530
Notches for sheeting trenches, 223
Notes should be initialed by a note-taker, 40
  note-books, 41
Numbering clauses in specifications, 465
Nye steam vacuum pump, 71

Oakum gaskets, 318, 331, 335
Obstruction of sewers, detection, 492
Office work, branch records, 305
    computations, 40
    cost keeping, 43
    drawings, 41
    manhole records, 305
    mapping, 18
    profiles, 21
Ogden, H. N.; rock excavation, 103
Oiling forms, 429
Oil in sewage cements deposits, 494
    separator, 536
    to kill mosquitoes in catch-basins, 516
Operation of sewerage system, cost, 522
Orange-peel buckets, 98, 99
Ordinance against inflammable liquids, 538
O'Shaughnessy, M. M.; classification of excavation, 56
Outfall sewers, profiles, 14
    surveys for, 29
Overfilling asphalt joints, 341
    cement joints, 331
    tar-cement joints, 342
Overhead charges, recorded in cost-keeping, 46, 49

P

Paraffine oil for lubricating forms, 429
Parmley, Walter C.; bond in brickwork, 354
    concrete block sewers, 362
Pavements, preserving materials, 60, 466, 468
    reconstructing, 466, 468
    records, 3, 17
    removing, 60
    replacing temporarily where settlement is anticipated, 36, 310
Pawtucket, R. I.; cleaning catch-basins, 510
Payments, brickwork, 479
    catch-basins and inlets, 487
    concrete, 482
    contract clauses, 459
    excavation, 469
    laying pipe, 486
    manholes, 488
    piling, 472
    reinforcement bars, 482
    shoring, 470
    vitrified pipe, 483
Peeling, with metal forms, 407, 429
Pensacola, laying outfall, 328
Percentage contracts, 448
Percussion drills, 105
Petrolatum for oiling forms, 430
Philadelphia; explosions in sewers, 530
    specification for measurement of sewers, 158
Phosphine, auto-combustible gas, 534
Photographs, desirability, 43, 81
    contract drawings, 454
    preserving, 43
    taken by inspectors, 35
Pierson, Geo. S.; brick and mortar required for sewers, 357
Piles, cutting off, under water, 321
    maintain grade of sewers in settling streets, 304
    refusal in driving, 472
    specifications, 472
    under cast-iron outfall, 326
    under concrete pipe sewer, 317
Pile drivers, extension leads, 326
    steam, 246
Piling, steel sheet, 241
Pipe, broken, 215
    buggy, 300
    cast-iron, inspection, 81
        laying, 317, 323, 328
            specifications, 486
    cement, 349
        jointing, 333
        specifications, 484
    concrete, 349
        laying, 316
    floating, 326
    for percussion drills, 107
    friction with compressed air, 124, 125
    grade line defined, 464
    heating by burning jute, 337
    joints, asphalt, 339
        cement, 331
        clay, 330
        filtite, 345
        flexible, 321, 323, 326
        G-K compound, 342
        jointite, 345
        leadite, 331
        marbleoid, 345
        Stanford, 330
        subaqueous, 325, 326
        sulphur-sand, 336
        tar, 339
        tar-cement, 342
    laying, cast iron, 317
        cost, 312
        cost-keeping, 44
        Iowa requirements, 307
        large concrete, 316
        rate of, 313
        specifications, 484
        steel, 319
        subaqueous, 320
        vitrified, 291
    locating by test pits, 5
    pulling into place, 328
    record of location, 3
    steel, 319, 322, 327, 328

Pipe, subaqueous, 320
  vitrified, 291
    discounts, 292
    handling and sorting, 299
    inspection, 293
    jointing, 330
    laying, 301, 485
    lengths in carload, 292
      in wagon load, 299
    sockets, 332
    specifications, 482
    tests, 295
  when used for sewers, 348
Pittsburg, Pa.; arbitration clause in contract, 439
  explosions in sewers, 528
Plank cap, 263
  clamp, 262
  lower, 217
Plans, checking old, 5
  contract, 22, 42, 453
  mapping, 19
  record, 41
Plant, cost keeping, 48
  selection, 382
  tendency to use too much, 54
Plaster of Paris for stemming, 143
Plastering exterior of brick sewer, 354, 479
Platforms, staging, 219
  under sewers, 303
  specifications, 473
Plowing street surfaces, 59
Plug and feathers, 101
Pneumatic tunneling, methods, 258
  when needed, 63
Poling boards, trench bracing, 234
  tunneling, 250
Population, records needed, 17
Porter, Rufus K.; driving tunnel in loose sand, 252
Post route maps, 2
Potter, Alexander, sulphur and sand joints, 337
  tar-cement joints, 341
Prelini, Charles; explosives, 130
  methods of tunneling, 65
Potter excavator and conveyor, 91
  hoister and conveyor, 90
Powder, ammonia, 134
  Atlas, 132
  black or gunpowder, 130
  contractors' or Judson, 131, 133
  Giant, 132
  Horsley, 133
Preliminary investigations for sewerage design, 1
  field work, 3
  maps, 2
  office work preliminary to design, 18
Preliminary, organization of engineering department for construction, 22
Pressures, earth, 271
Priming dynamite cartridges, 142
Printing contracts and specifications, 455
Prismoidal formula, 158
Profiles, brick-laying, 355, 396, 397
  for payments, 38
  information to be shown on, 21
  preliminary surveys, 4, 17
  record, 42
  Rochester outfall sewer, 14
Progress, brick sewer masonry, 360
  contract requirements, 457
  effect on costs, 54
  keeping records, 51
  length of centers affects rate of progress, 409
  pipe-laying, 313
  placing concrete, 393, 399, 401, 406, 410
  rates attained in building sewers, 195
Property lines, records, 3
Proposal, form for, 442
Proske, T. H ; sharpening drill bits, 116
Providence, R. I.; cleaning catch-basins, 512, 513
  sewer cleaning tools, 507
Puddling backfilling, 309, 311
Pulling pipe, 328
  sheeting, 239
  steel sheet piling, 246, 247
Pulsator for electric-air drill, 110
Pulsometer, 70
Pumps, centrifugal, 68
  diaphragm, 67
  reciprocating, 69
  sand, on wash drill rod, 13
  steam vacuum, 69
    Emerson, 72
    Nye, 71
    pulsometer, 70
Pumping, specifications, 471
Punch boring, 6

Q

Quantities, alteration of, in contract, 458
  brickwork, 351, 357
  concrete, 372
  trench excavation, 153
Quartsite, drilling 115
Quicksand, 276
  bottom work in trenches in, 302, 303
  sheeting trenches in, 81
Quincy, Mass.; cleaning sewers, 499, 505

R

Rags in sewers, 495

Rails, guard, 220
Railways, industrial, 379
  street, location records, 3
Rainfall, effect on trenches, 270
  records needed, 18
Rammers for tamping backfilling, 309
Rangers, 214
  bracing, 216
  difficult to hold against steel sheet piles, 246
  length, 216
  placing, 215, 228, 265
  quantity required, 222, 225
  size, 219, 222, 281, 286
  times used, 224
Rankine, W. J. M.; earth pressures, 280
  formula for earth pressures, 271
Rate of progress on construction, 195
  brick sewer masonry, 360
  contract requirements, 457
  effect on costs, 54
  keeping records, 51
  length of centers affects rate of progress, 409
  pipe-laying, 313
  placing concrete, 393, 399, 401, 406, 410
  rates attained in building sewers, 195
Reaming edge of drill bit, 116
Reciprocating drills, 105
  pumps, 69
Records, borings, 17
  branches, 305
  drawings, 41
  manholes, 305
  preliminary survey, 3
  sewerage system, Boston Society, 517
  taken during sewer construction, 40
  vitrified pipe receipts, 295
Reference marks, for trenches, 25
Refilling trench below pipe, 467, 468
Regulations against discharge of inflammable liquids into sewers, 538
Regulators, inspection, 491, 517
Reinforcement, placing, 384, 406
  specifications, billet-steel, 475
    rail steel, 477
    placing, 482
Rendrock, 132
Repose, angle of, 268
Repairs, by maintenance force, 516
  contractor's responsibility, 460
Richards, E. P.; disintegration of concrete sewers, 370
Rivers, data furnished by preliminary investigations, 5, 17
  surveying across, 29
  subaqueous pipe laying, 321
Rochester, N. Y.; profile of outfall sewer, 14
  wash borings, 12
Rock, excavation defined, 55, 467
Rock, from trench used in concrete, 371
  handling in trenches, 127
  in backfilling, 128, 310, 471
  lines of excavation, 152
  measurement, 158
  steps, cost, 161, 79, 268
  stripping, 468
Rods, copper spoon, for unloading blast holes, 144
  for determining grades of sewers, 4
  leveling, 3
  sewer cleaning, 507
  sounding, for ascertaining soil characteristics, 6
  transferring grades in trenches, 28
Rolling backfilling, 310
Roots, in sewers, 332, 495, 499
  in underdrains, 75, 495
  removing, 499, 501
Rope, hook, 300, 353
Rosette bit, 119
Ross, C. W.; root cutter, 499
Rotary drills, 15, 105
Round edge bit, 118
Rubble concrete, 481
  masonry, 480
Run-off, records desired, 5
Rupture, modulus of pipe, 298

S

Salem, Mass ; subaqueous outfall, 324
Salt in water for concrete, 393
San Francisco, Cal.; classification of excavation, 56
Sand, angle of repose, 269
  deposits in sewers, 495
  determination of organic matter, 33
  fine, for waterproofing concrete, 386
  inspection, 32
  pump on wash-drill rod, 13
  qualities desired for mortar, 32, 353
  running or quicksand, 276
  sharp, 353
  shoring trenches in, 267
  specifications, 474
  sulphur and sand jointing mixtures, 336, 338
  using, from trench, 371
  voids, 372
  washing, 371
Sanitary conveniences on work, 456
Saunders, W. L.; explosives, 130, 135
Scale, mill, removal, 34
Scales, Geological Survey maps, 2
  Post Office maps, 2
  record drawings, 42
  underground structures map, 18
  topographic maps, 20
Schist, drilling holes in, 103

Scranton, Pa.; map of underground structures, 19
Scrapers, drag, cost of excavation, 161
  for trench work, 98
  sewer, 501
  wheel, cost of excavation, 161
Screeding inverts, 384, 396, 399
Screenings, in mortar, 353
Sedimentation, acid used to hasten, 11
Separators, gasoline, 566
Settlement of ground and buildings, cause and prevention, 79
  inspector should guard against, 34
  instances, 229, 230, 304
Sewers, brick, 349
  choice of materials, 348, 367, 414
  cleaning, 501
  concrete, 367
    block, 362
  construction in narrow alley, 378
  cost of operation and maintenance, 522
  deposits, 493
  examination of, 5, 17, 492
    dangers of, 492
  explosions in, 492
  flushing, 496
  grades, 26, 41
  investment in American cities in, 491
  joints in pipe, 330
  length, measurement, 158
  obstructions, 492
  outfall, 322, 323, 324, 325, 326, 327, 328
  pipe, construction, 291, 330
  rates of progress, in building, 195
  smoothing inner surfaces, 335, 384
  transferring line and grade, 26
  vitrified block, 361
  waterproofing, 385
Shafts, tunnel, 64
Shale, excavation by steam shovels, 160
Sharp, quality in some sands, 353
Sheeting, bevel edges, 219, 240
  box, 232
  clamp, 262
  depth relative to bottom of trench, 217
  driving, 217, 241, 248
  excavating below end, 217
  for wet trenches, 79
  horizontal, 232
  jetting, 238
  length, 220
  lumber, 239
    amount-required, 222
  necessity for, 214
  notches, 223
  poling boards, 234
  pulling, 239
  removal, inspection during, 35
  skeleton, 237
  specifications, 469
Sheeting, thickness, 285
  times used, 223
  vertical, 215
  widths, 240, 263
Sheet piling, steel, 241
  driving, 247, 248
  pulling, 246, 247, 248
  used for deep trench in water, 325
Shield tunneling, 258
Shoring, box sheeting, 232
  necessity in trenching, 214
  poling boards, 234
  practical suggestions, 264
  requirements of different materials, 267
  skeleton sheeting, 237
  specifications, 469
  stay bracing, 236
  tunnels, 251
  vertical sheeting, 218
Shot drills, 15
Shoulders in bottom of trench, 153
Shoveling from trenches, 60
  staging platforms, 219
Shovels, steam, 93
  cost of excavation, 160
Sidewalks, keeping passages clear during excavation, 468
  specifications, 488
Siphons, inverted; inspection, 491, 517
Skeleton sheeting, 237
Sieves, round holes corresponding to square meshes, 32, 33
Simmons bit, 118
Snelling, Dr. Walter O.; selection of explosives, 136
Snow, F. Herbert; stoppages in sewers, 495
Soap and alum for making concrete impervious, 386
  used on forms, 430
Sockets, Coffin's study of shape, 335
Soil, adhesion, 270
  angle of repose, 268
  calculation of pressures, 271
  changes in character, 270
  cohesion, 269
  investigations of character, 6
  records of character, 40
Sounding with rods to ascertain soil characteristics, 6
South Bend, Ind., cost of centers, 426
Spacing drill holes, 103, 105
Specifications, absorption by vitrified pipe, 296
  backfilling, 471
  bearing strength of vitrified pipe, 297
  billet steel reinforcement bars, 475
  bituminous joints for pipe sewers, 341
  blasting, 470
  castings, 478
  catch-basin, 487

Specifications, cement, 473
  pipe, 484
 cleaning forms, 429
 concrete, plain and reinforced, 480
 curbing, gutters and sidewalks, 488
 earth excavation, measurement, 152
 engineer's rulings govern, 459
 excavation, 467
 foundations, 473
 general, 463
 inlets, 487
 laying cast-iron pipe, 486
  vitrified pipe, 484
 length of sewers, 158
 manholes, 487
 masonry, brick, 478
  stone, 479
 mortar, 475
 piling, 472
 pipe laying, 307, 484, 486
  sewers, 345
  vitrified, 482
 preparation of, 22, 435, 465
 printing, 455, 463, 465
 pumping, bailing and draining, 471
 rail steel reinforcement bars, 477
 reinforcement, 475, 477
 shoring, 469
 steel reinforcement, 475, 477
 technical, 466
 tunneling, 469
 wellholes, 487
Spoon, cleaning drill holes, 105
 copper, for unloading blast holes, 144
Sprague, N. S., Jr.; explosions in sewers, 527
Springfield, Mass.; cleaning sewers, 499
 laying steel pipe, 319
Square cross bit, 118
St. Louis, Mo.; cableway used on sewer trenches, 93
 crushing rock from trench for concrete, 371
 soundings in earth, shale and hardpan, 7
 steel pipe laying, 320
Stadia, use on surveys of outfall sewers, 30
Staging platforms, 219
Statistics of sewerage systems, form, 518
Stay bracing, 236
Steam, cleaning drill holes with, 142
 drills, 105
 hammers, 246
 shovels, 93
  cost of excavation by, 160
 thawing frozen ground, 59
 vacuum pumps, 69
Steel, reinforcing, inspection, 33
  placing, 384
  specifications, 482
 quantity and cost, Louisville sewers, 186
Steel, sheet piling, 241
 specifications, billet-steel, 475
  rail steel, 477
Stemming for blast holes, 143
Stern, Eugene W.; earth pressures, 281
Stone, crushed, inspection, 33
  specifications, 474
 masonry, specification, 479
Stonite, 132
Stoping drill, 112
Stoppage of sewers, detection, 492
Stoppers for branches, 307
Storage, excavated material, 468
 pipe, 299
Street railways, records of location, 3
Streets, loosening surface, 59
 maps, 2
 passages to be left during excavation, 468
 pavements, preserving materials, 60, 466, 468
  reconstructing, 466, 468
  records, 3, 17
  removing, 60
  replacing temporarily, 36, 310
 records of sections, 4
Subaqueous pipe laying, 321
 rock excavation, 321, 323
Sulky derricks, 317
Sullivan Machinery Co.; core drilling, 15, 16
Sulphur-sand mixtures, 336
Sumps in trenches, 78
Supervision, 30
 cost, 52
Supplies, cost keeping, 50
Surety, interest in changes in contract, 436
Surveys, character of soil, 6
 grades for excavation of areas, 29, 38, 39
 note-book for staking out sewer grades, 41
 preliminary, 3
 quantity, 158
 sewers, 25
Sylvester waterproofing process, 336
Syracuse, N. Y.; laying large concrete pipe, 316

T

Talbot, A. N.; pipe testing machine, 295
Tamping blast holes, 143
 backfilling, 301, 309, 311
  specifications, 471
Tappet valve for drills, 106
Tar binds deposits in sewers, 494
 joints in pipe sewers, 339
Tar-cement joints in pipe sewers, 342
Taylor, Alexander, J.; tamping backfilling by machine, 312

Taylor & Thompson; materials for strong concrete, 374
  proportions for strong concrete, 374
  quantities of sand, stone and cement, 372
  salt in water for concrete, 393
Team insurance, 444
Temperature of explosions of powder, 130
Tempering bits, 119
Templates for screeding inverts, 383, 396
Tests, brick, 351
  cement, 473
  density of concrete, 373
  general principles of specifying, 348
  iron castings, 478
  pipe sewers, 345
  reinforcing steel, 476, 477
  vitrified pipe, 295
Thawing, dynamite, 139
Thompson sewer cleaning machine, 503
Thomson, T. Kennard; earth pressures, 280
Timber, bill of materials for shoring, 224, 225, 226
  bill of materials full-round forms, 418
  for wood forms, 424
  kinds used for shoring, 239
  losses, 223
Timbering tunnels, 249, 264
Time forms should be in place, 430
Toad-stools in sewers, 495
Tools for cleaning sewers, 507
  cost keeping, 48
  sheeting, bracing and timbering, 261
Topography, map of Cincinnati, 20
  preliminary surveys, 4, 21
Townsend, A. C.; grease in sewers, 494
Tracings, care of, 42
Transportation, concrete, 379, 381
  explosives, 147
  vitrified pipe, 292
Trap, gasoline, 536
  rock, drilling holes in, 103
Treatment works, laying out, 29
  measurement of excavation, 39
Trenches, bottom narrowed, 153, 302
  backfilling, 309
  blasting in, 150
    cost, 151
  casting material from, 60
  changes in sides on exposure, 270
  cross-sections, Hopedale, 152
    Louisville, 227 to 237
  depth at Louisville, 173, 201
    where machine excavation becomes advisable, 82
    where tunneling is preferable, 62
  difficulties in soft bottoms, 302
  draining, 67, 302
  excavation below pipe in rock cut, 56, 128, 301
Trenches, hand excavation in bottom where machines are used, 99, 467
  laying out, 25
  length opened, 467
    with concrete sewers, 383
  lighting and guarding, 456
  materials from, in concrete, 371
  machines for excavating, 83
  must be dry for cement jointing, 75, 332, 486
  no adhesion between backfilling and bank, 270
  puddling, 309
  refilling below pipe, 467
  rolling backfilling, 310, 311
  shaping bottom, 301, 307
    specification, 485
  sheeting below underground structures, 236
    depth to be driven, 217
    different methods, 214, 264
    for steam shovel work, 94
    in different materials, 267
    on curves, 238
    pressures, 271
    quicksand, 81, 276
    rock cuts, 268
    wet trenches, 79
  spacing blast holes, 105
  specifications, 467
  starting work, 59
  steam drills in, 107
  width, affected by material, 151
    for machine excavation, 82
Trestles, subaqueous pipe laying, 322
Triangulation, cost, 21
  purpose, 3
Troughs, concrete, 381, 382
Tunnels, cost in different materials, 63, 196
  drill mountings, 108, 113
  effect of fumes from explosives, 137
  handling materials, 64
  in sand and gravel, 252
  lighting, 64
  lining, 67, 258
    forms, 412
    inspection, 36
    where used, 61
  pneumatic work, 63, 258
  rate of progress, 196
  shafts, 64
  steam drills used on short tunnels, 110
  timbering, 249
  ventilating, 64
Turbine sewer cleaner, 502

U

Underdrains, 75
  grading material around, 77

Underdrains, size, 76, 302
  specifications, 471
Underground surveys, maps of, 18
  sewers, 5
  soil, 6
Unit prices, advantages in rock and earth trenches, 57
  contracts based on, 446
Unloading dynamite from holes, 144
U. S. Geological Survey maps, 2
U. S. steel sheet piling, 242, 244
U. S. Weather Bureau records, 18

V

Valves for percussion drills, 106
Vancouver, B. C.; pulling pipe into place, 328
Velocities to prevent solids settling, 500
Ventilation, tunnels, 64
Vertical sheeting for trenches, 218
Vigorite powder, 133
Vitrified brick, specifications, 479
Voids in sand and gravel, 372
Vulcan sheeting hammer, 248
Vulcanite powder, 133

W

Wagon-load of pipe, 299
Wait, John Cassan; arbitration clauses in contracts, 437
  essentials of a contract, 434
Waite, Henry M., topographic maps, 20
  underground survey of Cincinnati, 2
Waling boards, in tunneling, 255
Walsall, England; sewer cleaner, 500
Waltham, Mass.; flushing sewers, 497
  obstructions of sewers, 496
Warrington steam hammer, 248
Wash boring, acid used to hasten precipitation of samples, 11
  N. Y. Commission on Additional Water Supply, 10
  U. S. Geological Survey, 8
Washing brick sewers with cement, 355
  concrete before resuming laying, 391
  sand and gravel, 371
Washington, D. C.; cleaning and oiling catch-basins, 516
  ordinance against inflammable liquids, 538
Wastes, industrial, regulations regarding discharge, 496
Watchmen, 456
Water, consumption, records, 18
  effect on cohesion of earth, 269
  for flushing sewers, 497
  in drill holes, 138, 142
Water, leakage into sewers, gaging, 5
    inspection, 37, 348
    permissible amount, 36
    through tar-cement joints, 342, 345
Water jet, cleaning dredged trench, 324
  drilling rigs, 8
  driving sheeting, 238
  loosening material for suction dredge, 325
    sheeting, 35
  lowering submerged pipe, 321
Waterbury, Conn; cost of wood forms, 426
Waterproofing, 385
Watson, Hugh S.; leakage in pipe sewers, 345
Weber Co.; wooden forms for large concrete sewer, 401
Webster, Geo. S.; explosions in sewers, 530
Wedges for quarrying by plug and feathers, 101
Wellholes, specifications, 487
Wells, jetting apparatus and methods, 9
Wemlinger steel sheet piling, 243, 245
Westboro, Mass.; fungus in sewers, 499
Wetherbee, George A.; cleaning sewers, 498
Wheelbarrows for concrete, 379
Wheel scrapers, cost of excavation, 161
Williams, Frank C.; full-round wood forms, 415
  sections of Louisville trenches, 227
Williams, William F.; submerged outfall at New Bedford, 325
Wilmington, Del.; tamping backfilling by machinery, 311
Windows in sheeting trenches, 223
Wing dams, 321
Winston, N. C.; sewer cleaning, 501
Wiring, blasting holes, 146
Wooden forms for sewers, 397, 399
  metal-covered, 403
Worcester, Mass.; absorption tests of sewer brick, 352
  air locks of pneumatic tunnel, 259, 260
  cleaning catch-basins, 512
    sewers, 508
  cost of operation and maintenance of sewerage system, 522
    of wood forms, 425, 426
  electric tunnel locomotive, 64
  experience with Carson trench machines, 89
  recording location of manholes and branches, 305
  rock tunnel with earth roof, 250
  tunnel in hard clay, 251
  use of drill sharpeners, 120
  wooden lining of pneumatic tunnel, 258
Work, abandoned, 458

Work, emergency and night, 456
  extra, 459
Workmanship, first class and poor, 38, 348
  good, essential on timbering, 264
  inspection, 34
Workmen's compensation, 443
Wrapping cloth about pipe joints, 332

X

X-bit, 118

Y

Y-bit, 118

Z

Z-bit, 119